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DRAFT
OU1 IN SITU REMEDIATION PILOT PROGRAM EVALUATION REPORT

SHIELDALLOY METALLURGICAL SUPERFUND SITE
NEWFIELD, NEW JERSEY

TRC Job No. 112434ES

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EXECUTIVE SUMMARY

This Draft Operable Unit 1 (OU1) In Situ Remediation (ISR) Pilot Program Evaluation Report (ISR Evaluation Report) is presented within this document for the Shieldalloy Metallurgical Corporation (SMC) Superfund Site located at 35 South West Boulevard in Newfield, New Jersey (hereinafter designated as "Site"), shown in Figure 1. The 2010 Administrative Order on Consent (AOC) defines OU1 as non-perchlorate (and non-radiological) groundwater. ISR at OU1 is being field tested to expedite the remediation of the contaminated groundwater. This ISR Evaluation Report satisfies the reporting requirements of the AOC Task IV, paragraph G.

<u>Site Background</u>

The SMC Facility ("Facility") was previously used for the production of specialty metals from 1955 and ending in 2007. Prior to 1955, the Site was used for the manufacture of glass. Since, 2007, the Facility is currently used for general warehousing/leasing and administrative purposes. During metals manufacturing operations, wastewater was handled in onsite lagoons. Environmental remediation activities have been ongoing at the Site for over 30 years, which included extensive environmental sampling and monitoring and studies, closure of the lagoons (under regulatory oversight), and construction/operation of a groundwater pump and treat system.

The Site has an extensive monitoring well network as shown on Figure 2, including approximately 100 monitoring wells and over 100 injection wells. The groundwater pump and treat system was operated from 1989 to 2013 (24 years). The 2010 OU1 Optimization Study found that groundwater pump and treat system provided reasonably good containment, but that concentration reduction rates from the pump and treat had slowed to asymptotic conditions since 2000. ISR techniques are being studied and implemented to expedite aquifer cleanup beyond the abilities of pump and treat technologies, to achieve cleanup goals faster.

The OU1 area is served by public water, and is protected by a well restriction established as an institutional control by the City of Vineland.

The Cohansey Formation is the primary formation regarding OU1. The total thickness of the Cohansey Formation under the Site is approximately 120 to 130 feet. The saturated thickness of the Cohansey Formation at the Site is approximately 100 feet. The Cohansey consists of light-colored (tan to pink, orange, brown and red), fine to coarse-grained sand and some gravel and silt with discontinuous layers and stringers of sandy clay and silt. The soil grain size within this formation is heterogeneous both vertically and horizontally. The Cohansey sand, which dips southeast approximately 0.2%, is the principal aquifer in the region. The underlying Kirkwood Formation acts as a confining layer and restricts the downward flow of groundwater from the Cohansey Sand.

Hydraulically, the Cohansey Formation behaves as a single heterogeneous, water table aquifer. For the purposes of in situ remediation designs, TRC simplified the analysis and considered two in situ treatment zones – the upper zone and the lower zone as detailed below (with appropriate adjustments based on location-specific conditions):

- Upper Zone: interval varied between 15 to 75 feet bgs.
- Lower Zone: interval varied between 80 to 140 feet bgs

The depth to groundwater within the aquifer ranges from approximately 4 feet bgs in the southern portion of the Site to approximately 16 feet bgs in the northern portion of the Site.

Chromium is the primary groundwater contaminant of concern at OU1; TCE is the secondary contaminant of concern. The OU1 chromium plume extends in the direction of the groundwater flow, southwest, from the Facility, past the Car Wash, and is contained at the Farm Parcel (1/2 mile from the Facility). The OU1 TCE also begins at the Facility, and extends southwest of the Farm Parcel (2.5 miles from the Facility). Offsite sources of TCE (and other chlorinated volatile compounds) have been identified between the Facility and the Car Wash, which are believed to have contributed to the TCE plume (in fact these other sources also contributed PCE to the plume).

ISR Program Overview

The ISR pilot program has been progressive and aggressive. The ISR pilot program started with white paper studies and jar studies in 2007, and evolved to more extensive bench-scale tests, trying a variety of injection materials and combinations through 2010. Results indicated that calcium polysulfide (CPS) would be an effective amendment to treat chromium-impacted groundwater. CPS fosters chemical transformation by reducing the valent state of chromium from hexavalent to trivalent (the less toxic and less mobile form) and simultaneously shifting geochemical conditions to precipitate the chromium out of solution. Treatability testing results also showed that emulsified vegetable oil (EVO) would be an effective amendment for the secondary groundwater contaminant, TCE. EVO fosters biological transformation, by providing microbes a carbon "food source" and an electron donor for respiration of TCE. EVO fosters microbial growth, and specialized microbes reductively dechlorinate TCE to harmless end products (*e.g.,* ethene and/or CO_2).

Following the April 2010 execution of the Administrative Order on Consent (AOC), the ISR pilot program goals were established to validate laboratory studies with progressively larger-scale field injections in order to validate the ISR technology, reduce concentrations, reduce the time to cleanup, and foster natural attenuation. CPS and EVO injection tests targeting "single well" areas were conducted in 2010. Years 2011, 2012, and 2013 included broader-scale and iterative CPS pilot test injections. Also, EVO injections to address TCE were performed in 2011.

The conceptual remedial scheme for chromium treatment included the installation of rows of injection wells perpendicular to ground water flow (see Figure 3). The distance between injection rows was modeled for effective treatment of chromium between injection rows. CPS injected into the injection wells created an immediate reactive zone in and around the injection wells, and then CPS and geochemical changes "sweep" through downgradient aquifer treatment zones. This process is designed to dramatically shift the subsurface environment to both reduce dissolved chromium concentrations and foster long-term reductions in concentration via enhanced and natural attenuation. Geochemical adjustments include creating favorable oxidation-reduction potential (ORP), favorable pH and dissolved oxygen (DO) conditions. CPS injection also releases naturally-occurring iron into the groundwater from the aquifer matrix (high concentrations naturally available), which can further accelerate the reduction and precipitation of chromium. The CPS remains reactive for chromium remediation for a number of years. The ISR Pilot Program includes analysis of how long the CPS remains active in the subsurface, and at what point after injection this "active remediation" would shift to natural attenuation. It is noted that this process is a continuum, versus a sharp start/stop point. To date, approximately 87 tanker trucks (~3.9 million lbs) of 29% CPS solution have been injected into a network of over 100 injection wells with a monitoring network of approximately 100 monitoring wells. Much of the plume is still under active remediation as a result of these injections.

Additionally in 2011, an EVO injection and a bioaugmentation pilot program remediated the on-site source zone area for TCE near SC-20S and the former degreasing unit. Where the CPS is best injected in a line of wells perpendicular to groundwater flow, EVO injections work best to address the Site source area via injection of a grid of temporary well points. Similar to CPS, the EVO creates a reactive and reducing zone where degradation of contaminants may be fostered for several years.

This report evaluates the ISR Pilot Program consistent with the requirements of the AOC.

<u>ISR Results</u>

The ISR results for the Facility, Farm Parcel, and Car Wash, are discussed below.

Facility

The results from the Facility injections demonstrate:

- 95-99% reduction of average Cr & Cr(VI) GW concentrations in Facility wells [from 4,490 to 140 µg/L for total chromium and from 2,130 to 13 µg/L for Cr(VI)];
- Many Facility wells observed 98%-100% reduction in chromium conccentrations; and
- Enhanced natural attenuation capacity due to mobilizing native iron and improved geochemical conditions.

Farm Parcel

The results from the Farm Parcel injections demonstrate:

- Rapid geochemical shifts in treated portions of the aquifer that favor accelerated cleanup;
- Rapid and ongoing reduction of dissolved chromium concentrations in groundwater, namely;
    - ✓ 98%-100% reduction of Cr concentrations at some wells;
    - ✓ 93% reduction average Farm Parcel Cr(VI) concentrations (decreased from 4,909 µg/L to 347 µg/L);
    - ✓ 79% reduction average of Total Cr concentrations in wells within or near the treatment zone (decreased from 5,024 µg/L to 1,066 µg/L); and
    - ✓ Concentration reductions from the 2012 injections are stable (or continuing to decrease), based on comparison of Fall 2012 to Spring 2013 sampling results.

- Enhanced natural attenuation capacity due to mobilizing native iron and improved geochemical conditions; and
- Further, water recycling with recirculation sourced from the Farm Parcel recovery well, RIW-2, was successful and conserved water.

The ISR Pilot Program has demonstrated that CPS is an effective amendment, that injection wells are efficient means of delivery, and that the CPS loading rates utilized during the pilot test are effective in reducing dissolved chromium concentrations.

Farm Parcel results indicate, however, that there is a localized area (at and just downgradient of injection row 7) that has not achieved the desired concentration reduction at the time of this writing, due to a somewhat finer soil grain size (higher silt and clay content) in this localized area. Planned May/June 2014 targeted injections would overcome these location-specific conditions to better achieve program goals.

Car Wash

The results from the 2013 (initial) Car Wash injection demonstrate:

- Rapid geochemical shifts that favor accelerated cleanup;
- Rapid and ongoing (as the CPS continues to sweep through the aquifer) reduction of dissolved chromium concentrations, namely:
  - ✓ 98%-100% reduction of Cr concentrations at some wells;
  - ✓ 85% reduction average of Total Cr concentrations in Car Wash wells within or near the treatment zone (decreased from 1,329 µg/L to 196 µg/L); and
  - ✓ Average Cr(VI) concentrations decreased from 1,407 µg/L to 76 µg/L (94% reduction).
- Enhanced natural attenuation capacity due to mobilizing native iron.

<u>ISR Pilot Program Evaluation</u>

ISR Pilot Program Evaluation has included the evaluation of the following components:

- Chromium concentration reduction results and permanence determination;
- Assessment of the longevity of CPS activity;
- Chromium MNA evaluation summary;
- TCE concentration reduction results;
- Summary of TCE MNA evaluation; and
- Evaluation of ISR effectiveness, implementability, and cost.

Chromium Concentration Reduction Results and Permanence Determination

The ISR Pilot Program successfully reduced chromium concentrations throughout much of the plume. Concentration reduction percentages have exceeded 90% at the Facility and the Car Wash and have exceeded 80% at the Farm Parcel. Planned 2014 injections at the Farm Parcel are expected to increase the Farm Parcel chromium concentration reduction rate to above 90%. It has been verified, through geochemical analysis and the study of chromium concentrations over time, that these concentration reductions are stable and irreversible (i.e., permanent).

Assessment of the Longevity of CPS Activity

Based on a detailed assessment of geochemical parameters (notably pH and redox), the CPS treatment zones are still in an active remediation phase as a result of CPS injections. The CPS reagent remains active in the subsurface for a relatively long period of time. Continued remedial activity in the subsurface is noted at the Facility, which has not received injections in over a year. Transport modeling predicts that CPS could potentially persist (continue to exist at a reactive capacity) for approximately 5 years in the upper zone and 20 to 35 years in the lower zone, where higher doses of CPS were applied and the soil is less permeable. As CPS is consumed for chromium reduction, the aquifer will begin to shift towards more natural geochemical conditions. These estimates are included in Appendix A. As this shift occurs, natural attenuation will progressively become the more dominant remedial process. It is noted that this shift is a continuum, not a sharp start and stop point.

Chromium Monitored Natural Attenuation (MNA) Summary

TRC has been performing MNA evaluations at the Site. During 2013, TRC completed an evaluation of MNA for chromium in groundwater based on EPA's 4-criteria procedure, as requested (*21. TRC, February 2013*). The MNA evaluation concluded that chromium MNA is viable and appropriate for the Site, and set some initial target MNA concentrations goals. Regulatory input indicated a desire to perform additional MNA sampling under "non-pumping" conditions, and to perform more detailed MNA modeling. Following that regulatory direction, the pumping wells (Car Wash) wells were turned off, deactivating the pump and treat system in March 2013. TRC submitted an MNA monitoring plan and collected quarterly MNA data since April 2013. Further analysis of the data will be submitted under separate cover, after recent sample results are compiled and evaluated.

TRC also completed an MNA model of chromium fate & transport at the Site (*27. TRC, May 2013*) to further evaluate the feasibility of MNA. EPA's BIOSCREEN modeling program (*31. EPA, 1997*) was used to simulate advective-reactive transport, and natural attenuation of dissolved chromium in groundwater via sorption and chemical reduction/precipitation. The model inputs included site specific chromium concentration and mass, measured hydrogeologic characteristics, and retardation factors. The model incorporated multiple conservative assumptions (*e.g.*, taking highest well concentrations as base case, and assuming that injections would not further reduce concentrations, among others) to provide results that were safe and conservative. The model concluded that MNA is viable for the Site and would keep sentinel wells (select wells downgradient on the Farm Parcel) below regulatory standards over time. The model also calculated target allowable residual total chromium concentrations at the Farm Parcel, at which MNA is viable (*i.e.*, target concentrations that maintain sentinel wells below regulatory standards over time). Both average allowable and localized high residual total chromium "threshold" concentrations were developed for the upper and lower zones. The upper zone average allowable residual concentration is 750 µg/L total chromium, and the localized high residual "threshold" concentration is 1,000 µg/L total chromium. The lower zone average allowable residual concentration is 1,250 µg/L total chromium, and the localized high residual "threshold" concentration is 2,700 µg/L total chromium.

Initial MNA monitoring (per TRC's 2013 MNA Monitoring Plan) will be completed in April 2014. Results of this initial MNA monitoring will be submitted in the 2014 Groundwater Annual Report. Analysis of results thus far generally indicate that chromium concentrations within the active CPS injections areas have decreased significantly. The injection process) and associated physical and geochemical perturbations) has induced a locally agitated environment, not consistent with true MNA conditions. Steady MNA conditions (not impacted by the injections) should develop after the aquifer has stabilized physically and geochemically and until the CPS plume is stabilized or exhausted (as discussed above). This is a positive condition because it means that active remediation is ongoing. Routine monitoring should continue, to assess the chromium concentrations over time, and to evaluate when CPS is exhausted at various Site locations. At that point, additional MNA statistical evaluations could be performed.

TCE Concentration Reduction Results Summary

TRC's January 2011 Pre Design Investigation Report (*1. TRC 2011*), approved by EPA March 14, 2014, studied TCE in detail, both on the Facility and offsite. That report concluded that only a small "residual source" area of groundwater existed at the Facility (at the location where solvents were used in the north/central part of the site). It is noted that the OU2 Remedial Investigation concluded that there were no detections of VOCs in Facility Soil (including the solvent use area) so the only "residual source" was in groundwater. In situ injections of emulsified vegetable oil (EVO) plus nutritional additives and bioaugmentation culture were injected at the Facility around the residual source location in 2011. Prior to EVO injection (2010) the key well concentration (SC-20S) was 207 µg/L TCE. Following 2011 EVO injections, the TCE concentrations were non-detect. Sample results in 2013, two years after the injections, demonstrated that the TCE concentrations at this location continue to be non-detect. It is concluded that the Facility TCE "source" concentrations have been remediated. Concentrations of TCE at the southwest property corner have generally varied, on average, from 10 to 20 µg/L between 2010 and 2013, slightly above the regulatory NJDEP Ground Water Quality Standards (GWQS) of 1 µg/L. It is common that CVOCs concentrations fluctuate over time at relatively low concentrations due to seasonal changes and geochemical conditions.

TCE MNA Summary

The 2011 Pre Design Investigation Report, approved by the EPA in March 2014, concluded that TCE concentrations, namely, those downgradient of the Facility and Farm Parcel, were properly delineated and, further, that MNA is viable and appropriate for TCE, based on the Tier IV EPA analysis. Further, that report indicated that the plume at and downgradient of the Car Wash and Farm Parcel is attributed to non-SMC sources.

Evaluation Versus EPA's Screening Criteria
The AOC requires that the ISR Pilot Program be evaluated against EPA's screening criteria of effectiveness, implementability, and relative cost.

Effectiveness
EPA's effectiveness criterion focuses on the effectiveness of the technology to reduce toxicity, mobility or volume of contamination for long-term protection and in complying with project objectives. The criterion also evaluates how proven and reliable the process is with regards to site-specific conditions.

The ISR Pilot Program has effectively reduced the toxicity and the mobility and the volume of the chromium contamination. The toxicity has been reduced by the conversion of chromium from the soluble hexavalent chromium form to the less toxic and more immobile trivalent form. The mobility has been reduced because, as part of the ISR process, chromium has precipitated out of solution, into its far less mobile form. The volume (the overall footprint of the chromium plume hotspots above regulatory standards) has been reduced, by greater than 80% and 90%. Further, evaluation of geochemical conditions, as well as chromium concentrations trends over time, have shown that these positive changes are permanent (stable and irreversible), proven, and reliable such that the changes provide long-term protectiveness. Similarly, the highest areas of SMC TCE concentrations have been reduced (from 207 ug/L to non-detect) and have remained ND over time. So the TCE reductions are permanent.

ISR is highly effective.

Implementability
EPA's implementability criterion focuses on both the technical and administrative feasibility of the technology, and includes evaluation of pre-treatment requirements, residual management, and the relative ease or difficulty in performing the operation and maintenance (O&M) requirements. Technologies that are ineffective or unworkable at the Site are eliminated by this criterion.

ISR has been readily implemented with commercially-available material and equipment. Administrative requirements of the ISR Pilot Program have generally included government approval of workplans, and the issuance of Permit-by-Rule Equivalences. The government has provided these administrative requirements in a timely and thorough fashion. The ISR technology generates essentially no residuals or waste. After injections are complete, active remediation continues for years with little O&M (primarily focused on active monitoring), so the O&M requirements are reasonable. ISR is also remarkably sustainable.

Comparatively, the OU1 Optimization Study concluded that that the pump and treat technology reached a point of diminishing returns (asymptotic concentrations) by 2000. Further, evaluations herein, based on analytical modeling, have shown that pump and treat, if its operation had been indefinitely extended, would achieve regulatory standards for chromium in approximately 440 to 600 years (see Appendix B). The time to achieve regulatory standards for chromium for ISR (followed by MNA) is approximately 120 to 330 years (also in Appendix B). So, ISR improves the time to cleanup for chromium by two to three times. The time to cleanup for ISR for

Chromium can be revisited (possibly improved) after the 2014 injections are completed. Similarly, the time to remediate TCE under the pump and treat operations is projected to be approximately 80 to 100 years (see Appendix C). Whereas the time to remediate TCE under the ISR (followed by MNA) is approximately 30 to 40 years (also in Appendix C). So, ISR improves the time to cleanup for TCE by two to three times also. This time to cleanup is shorter (and better) for ISR than for pump and treat for both chromium and TCE.

Further pump and treat is administratively burdensome (extensive testing and reporting), and is unsustainable due to the extensive energy demand for operation and the significant amount of produced waste (750 million gallons of water wasted, plus hundreds of tons of landfill waste generated).

ISR is highly implementable. And pump and treat is poorly implementable. Further analyses in the forthcoming OU1 Focused Feasibility Study (FFS, requested by the EPA) will determine if the pump and treat technology should be further retained for consideration.

Relative Cost

EPA's relative cost criterion is based on engineering judgment; the technology being evaluated as to whether costs are low, moderate or high relative to other options of similar technology type. For purposes of establishing a comparison to ISR, TRC used pump and treat, the technology cited in the AOC.

TRC has spent $6,600,000 on the ISR Pilot Program. These investments have reduced shallow TCE concentration at the key well (SC-20S) 100%, and chromium concentrations by >95% in less than 9 months of injection work at the Facility and >90% at the Car Wash and Farm Parcel. Comparatively, the pump and treat system construction and operation cost approximately $30,000,000, reduced chromium plume volume by less than 50% over 20 years. While the ISR cost has been quite significant, the RELATIVE cost (cost accounting for results) for ISR is lower than for pump and treat.

Conclusion

In summary the evaluation of the ISR Pilot Program satisfies EPA's screening criteria. The ISR Pilot Program has dramatically reduced chromium concentrations, and has established an ongoing and active subsurface remedial environment. The TCE Facility source has effectively been remediated. MNA is viable and appropriate for both chromium and TCE. Target ISR chromium concentrations have been determined, and have largely been attained (planned 2014 focused injections will address the remaining chromium concentrations currently above the target concentrations). The diffused TCE concentrations are also at levels appropriate for MNA. In short, the ISR Pilot Program has exceeded expectations.

The ISR approach will be compared to the pump and treat approach in the forthcoming OU1 FFS.

1.0 INTRODUCTION

TRC prepared this Draft OU1 In Situ Remediation (ISR) Pilot Program Evaluation Report (ISR Evaluation Report) to assess the ISR work performed from 2007-2014 at the Shieldalloy Metallurgical Corporation (SMC) Superfund Site (hereinafter designated as "Site") located at 35 South West Boulevard in Newfield, New Jersey. A site location map is provided as Figure 1 and the Site Plan is provided as Figure 2. The ISR Pilot Program overview and report content are discussed in the following subsections.

1.1 ISR Pilot Program Overview

The ISR pilot program has been progressive and aggressive. The program started with white paper and jar studies in 2007, and evolved to more extensive bench-scale tests, trying a variety of injection materials and combinations through 2009. Early study results indicated that calcium polysulfide (CPS) would be an effective amendment to treat the primary contaminant, chromium. CPS provides a chemical reduction process that first changes the form of chromium from hexavalent to the less mobile trivalent, then fostering amenable geochemical conditions to precipitate the chromium out of solution. Further, CPS makes iron that exists on the native aquifer soil/sand particles more available (the iron, in its natural form, is well-adhered to the soil/sand, and the induced reducing conditions in advance of the CPS front help to release the iron). Bench scale testing results also showed that emulsified vegetable oil (EVO) would be an effective amendment for the secondary contaminant, TCE. EVO fosters a biological transformation process, by providing microbes a carbon "food source". This food source fosters microbial growth, and the microbes, in turn degrade the TCE.

Following the April 2010 execution of the Administrative Order on Consent (AOC), the ISR pilot program goals were established to validate laboratory studies with progressively larger scale field injections in order to validate the in situ treatment technology, reduce concentrations, and to study and foster natural attenuation. "Single well" CPS injection tests were conducted in 2010 and were followed by broad scale and iterative pilot injections in 2011, 2012, and 2013. In general, to address chromium, a line of injection wells, perpendicular to ground water flow, were installed. CPS injected into the injection wells would create an immediate reaction zone in and around the wells, then "sweep" through downgradient aquifer zones. This process, depicted in Figure 3, is designed to dramatically shift the subsurface environment to both reduce concentrations and foster longer-term concentration reduction via enhanced and natural attenuation. The CPS remains reactive for chromium remediation for a number of years. The ISR Pilot Program includes analysis of the longevity of CPS reactivity in the subsurface, and at what point after injection this "active remediation" would shift to natural attenuation. It is noted that this process is a continuum, versus a step-like process. To date, approximately 87 tanker trucks (~3.9 million lbs) of 29% CPS have been suitably injected (yielding very good results, discussed below) into a well network comprised of over 100 injection wells and approximately 100 monitoring wells over a ½ mile plume.

The TCE remediation, as discussed below, was better addressed by a grid of temporary injection points, which has also been successfully completed.

1.2 Report Content

This report is organized as follows:

- Section 2: Site Background;
- Section 3: ISR Evaluation;
- Section 4: Conclusion
- Section 5: References.

Supporting figures and appendices are also included, as appropriate.

2.0 ISR BACKGROUND

The ISR background includes the following components:

- Site overview
- Geology;
- Hydrogeology;
- Pre-existing geochemistry;
- Nature and extent of OU1 contamination;
- ISR pilot program progression; and
- ISR technical background.

These components are discussed in the subsections below.

2.1 Site Overview

The SMC Facility ("Facility") was previously used for the production of specialty metals from 1955 and ending in 2007. Prior to 1955, the Site was used for the manufacture of glass. Since, 2007, the Facility is currently used for general warehousing/leasing and administrative purposes. During metals manufacturing operations, wastewater was handled in onsite lagoons. Environmental remediation activities have been ongoing at the Site for over 30 years, which included extensive environmental sampling and monitoring and studies, closure of the lagoons (under regulatory oversight), and construction/operation of a groundwater pump and treat system.

The Administrative Order on Consent (AOC) for the Site was executed by the USEPA, TRC Environmental Corporation (TRC), and SMC on April 28, 2010 and defined Operable Unit 1 (OU1) as non-perchlorate (non-radiological) groundwater contaminated primarily by chromium and secondarily by TCE. The OU1 dissolved chromium plume extends from the Facility (former SMC manufacturing areas) southwest to the Car Wash area and then southwest to the Farm Parcel (a separate parcel never used for manufacturing, but purchased by SMC to facilitate operation of a pumping well and currently leased for farming), approximately ½ mile down-gradient from the Facility. A site location map is provided as Figure 1 and the Site Plan is provided as Figure 2.

The Site has an extensive monitoring well network as shown on Figure 2, including approximately 100 monitoring wells (and 100 injection wells). The groundwater pump and treat system was operated from 1989 to 2013 (24 years). The 2010 OU1 Optimization Study found that groundwater pump and treat provided reasonably good containment, but that concentration reduction rates had slowed to asymptotic conditions since 2000. ISR techniques have been studied to expedite aquifer cleanup beyond the abilities of pump and treat technologies.

The City of Vineland implemented and currently maintains a well restriction area for a large section of northern Vineland, which includes the area impacted by the plume. Further, the area within the well restriction is served by public water. TRC submitted an application for a Classification Exception Area (CEA) in 2001 to the NJDEP, as an additional protection and institutional control, but that CEA has not been approved, to date.

2.2 Geology

The Site is underlain by the Kirkwood-Cohansey aquifer system. The surficial soil is comprised of the Bridgeton Formation, which consists mainly of brown sands with a thickness that increases in a westerly direction from approximately 0 to 30 feet.

Underlying the Bridgeton Formation is the Cohansey Formation, which is the primary formation regarding OU1. The total thickness of the Cohansey Formation under the Site is approximately 120 to 130 feet. The saturated thickness of the Cohansey Formation at the Site is approximately 100 feet. The Cohansey consists of light-colored (tan to pink, orange, brown and red), fine to coarse-grained sand and some gravel and silt with discontinuous layers and stringers of sandy clay and silt. The soil grain size within this formation is heterogeneous both vertically and horizontally. The Cohansey Formation is composed predominantly of quartz. Secondary minerals are aluminum oxides and iron-containing minerals (*i.e.,* illites, kaolinite, and pyrite), which play a major role in the fate, transport and natural attenuation of contaminants in this aquifer.

The Kirkwood Formation, consisting of gray silts and clays, underlies the Site and serves as an aquitard. The depth to the Kirkwood Formation at the Site varies between approximately 120 and 140 feet bgs. Geological surveys suggest that the Kirkwood Formation is approximately 100 feet thick in the vicinity of the site.

2.3 Hydrogeology

The Cohansey sand, which dips southeast approximately 0.2%, is the principal aquifer in the region. The underlying Kirkwood Formation acts as a confining layer and restricts the downward flow of groundwater from the Cohansey Sand.

Hydraulically, the Cohansey Formation behaves as a single heterogeneous, water table aquifer. For the purposes of the ISR design, we simplified the analysis and considered two treatment zones:

- Upper Zone: The treatment interval for the Facility and Farm Parcel ranged between 45 feet bgs and 65 feet bgs. The treatment interval for the Car Wash ranges between 50 feet bgs and 75 feet bgs.
- Lower Zone: The treatment thickness averaged 10 to 25 feet at the Facility, and 30 feet at the Farm Parcel and the Car Wash and depth intervals that varied from 80 to 120 feet bgs (immediately above the top of the Kirkwood clay).

The depth to groundwater within the aquifer ranges from approximately 4 feet bgs in the southern portion to approximately 16 feet bgs in the northern portion of the Site. Seasonal fluctuations in the water table elevations are in the range of a few feet. The groundwater flow direction within the Cohansey aquifer at the Site is to the west-southwest along the Hudson Branch.

2.4 Pre-Existing Geochemistry

Prior to the ISR injection activities, the pre-existing geochemical conditions are summarized below. The primary geochemical parameters that affect ISR considerations are dissolved oxygen (DO), pH, and reduction-oxidation (redox) potential.

<u>DO</u>
Aerobic to anoxic conditions prevailed throughout the OU1 aquifer prior to ISR activities. DO levels ranged between 0.1 and greater than 5 milligrams per liter (mg/L), with most wells exhibiting DO levels above 2 mg/L. Localized zones of lower DO levels (below 1 mg/L) were occasionally observed which were at greater depths and near the former on-site lagoons. These lower DO levels were also usually coincident with areas of higher organic content (*e.g.*, wetlands) or higher dissolved iron content.

<u>pH</u>
Background OU1 groundwater pH generally ranged between relatively acidic to near neutral levels of 4 to 8 standard units (s.u.), except for monitoring wells near the former on-site lagoons where more variable and alkaline pH conditions were observed. Aquifer soil pH was mostly near neutral but varied between moderately acidic to slightly alkaline.

<u>Redox</u>
The pre-existing redox conditions in the OU1 aquifer were generally oxidizing with ORP measurements between +50 milliVolts (mV) to +350 mV with localized exceptions. Notably, anoxic and reducing conditions were observed at SC-20S, which is nearest to the TCE source area and are favorable conditions for enhancing reductive dechlorination.

The ISR Pilot Program has created beneficial changes to the geochemical conditions, conducive to contaminant concentration reductions, as discussed in Section 3.0.

2.5 Nature and Extent of OU1 Contamination

The nature and extent of OU1 contamination is discussed in the following sections for chromium and other metals, and TCE and other CVOCs.

2.5.1 Chromium and other Metals

Chromium exists in both hexavalent (Cr(VI)) and trivalent (Cr(III)) forms in OU1. NJDEP groundwater quality standards (GWQS) for chromium is 70 µg/L and EPA MCL for total chromium is 100 µg/L. Chromium has been detected in OU1 groundwater exceeding these regulatory levels, extending from the Facility, past the Car Wash, to the Farm Parcel. The chromium plume has been contained at the Farm Parcel. The chromium plume (prior to ISR work) was ½-mile long, and 400-feet wide, on average. The chromium plume was generally broader at the Facility (because of the former sources), and narrower at the Farm Parcel (generally consistent with the fate and transport nature in a sandy aquifer).

The asymptotic conditions appear to be sustained by defined zones containing higher residual chromium concentrations. Prior to ISR activities, chromium concentrations ranged between Not-Detected (ND) and 30,000 µg/L at the Facility and between ND and 18,000 µg/L at the Farm Parcel. The speciation of trivalent chromium, Cr(III), and hexavalent chromium, Cr(VI), varies somewhat throughout OU1, based on concentrations observed over 30 years. Chromium concentrations from the pumping wells have been asymptotic at approximately 1,000 µg/L for since 2000, based on the 2010 OU1 Optimization Study.

OU2 reporting summarizes that the lagoons (the historic source of OU1 chromium contamination) were properly closed, which included excavation and offsite disposal of soil and extensive post-excavation soil sampling. The OU2 reporting indicates that only 2 out of 220 soil sample results exceed risk levels and identifies these 2 exceedances as *deminimus*.

In order to confirm that these two exceedances do not negatively impact OU1, TRC herein reviewed data from the abundant groundwater monitoring data. The current well network at the Facility incorporates 92 wells that have been extensively monitored (quarterly) for over 20 years. The groundwater data clearly indicate that the shallow zone groundwater under the Facility, in general, and the lagoons, specifically, have chromium concentrations that are very low compared to the chromium concentrations in the intermediate and deep zones of the aquifer. It is therefore concluded that unsaturated soils do not serve as a source to OU1 contamination.

<u>Other Metals</u>
Other parameters in groundwater identified in initial OU1 investigations (reported in the 1991 FFS) include antimony, arsenic, beryllium, boron, cyanide, manganese, and vanadium. The exposure point concentrations, EPCs from 1995 are compared to the currently (2013) detected maximum concentrations and the GWQS below, in order to provide a current understanding of conditions:

Parameter	EPC-1995 (µg/L)	Maximum 2013 Concentration (µg/L)	NJDEP GWQS (µg/L)	Current Exceedance?
Antimony	2,100	1.8	6	No
Arsenic	750	1.5	3	No
Beryllium	570	0.17	1	No
Manganese	600	83.8	50	Yes
Vanadium	1,300,000	0.72	NS	No

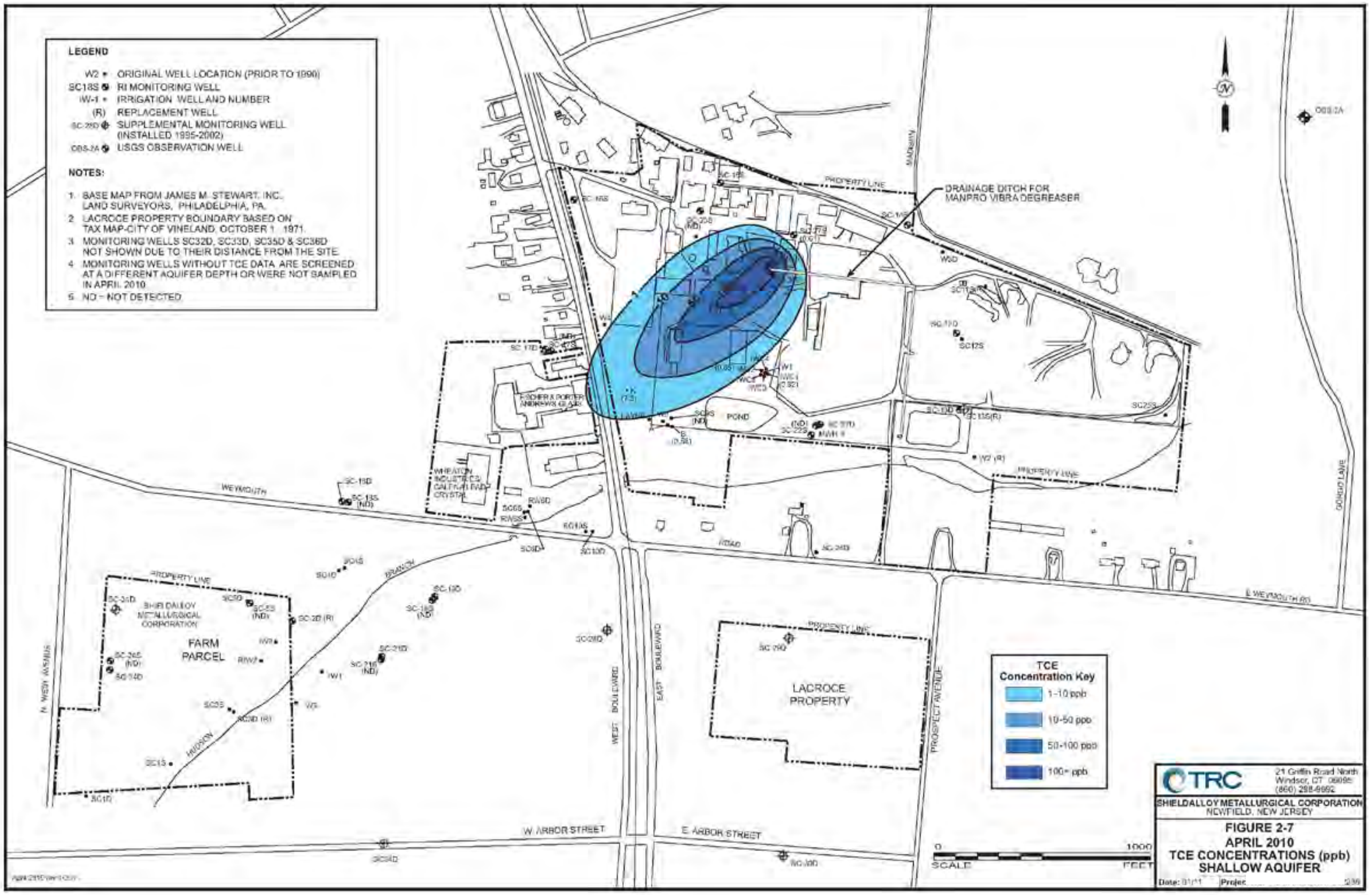
Notes:
NA=not analyzed
NS=there is no GWQS for vanadium. OU2 RI determined no groundwater vanadium risk.

These data indicate that the majority of parameters previously demonstrating risk no longer exceeds GWQS, except for manganese. Manganese, which occurs naturally, exists at concentrations almost on-order-of-magnitude less than existed in 1995. Some small exceedances (3 wells) still exist for manganese. These exceedances are in the same footprint as the chromium plume. MNA, discussed below, would be applicable to manganese as well as chromium. Boron and cyanide are not currently sampled, so comparison is not available.

2.5.2 TCE and Other CVOCs

TCE is the secondary contaminant of concern for OU1. In the 1980's, TCE concentrations from the pumping wells was approximately 100 µg/L. The 2010 Annual Groundwater Report (*54. TRC, 2010*) summarized the nature and extent of TCE in OU1 in 2010 (prior to significant ISR work). In 2010, a relatively focused TCE plume existed in the shallow aquifer zone, initiating in the north/central portion of the Facility (near well SC-20S, near the building where solvent was used), heading southwest, past the southwest Facility corner (wells K and Layne), towards the Car Wash. The plume, depicted in Graph 2-1 on the next page, was approximately 500 feet wide by 1,000 feet long, with the highest concentration of 207 µg/L (well SC-20S). ISR injections targeting TCE, as discussed in Section 3.0, have dramatically reduced the TCE plume. Both 2012 and 2013 results indicate that the concentration at SC-20S have been reduced without rebound from 207 µg/L to non-detect. This indicates that significant on-site TCE source remediation has been accomplished. TCE concentrations at the southwest Facility corner (wells K and Layne) continue to vary, from 2010 to 2013, from 1 to 70 µg/L with most results in the 1 to 20 µg/L range.

It is noted that the OU2 Remedial Investigation concluded that there were no detections of VOCs in Facility Soils (including the solvent use area) so the only "source" was in groundwater.



<u>Graphic 2-1 Pre-Injection April 2010 TCE Concentrations (ppb) Shallow Aquifer</u>
<u>NOTE: Post Injection TCE Concentrations for this well are Non-Detect</u>

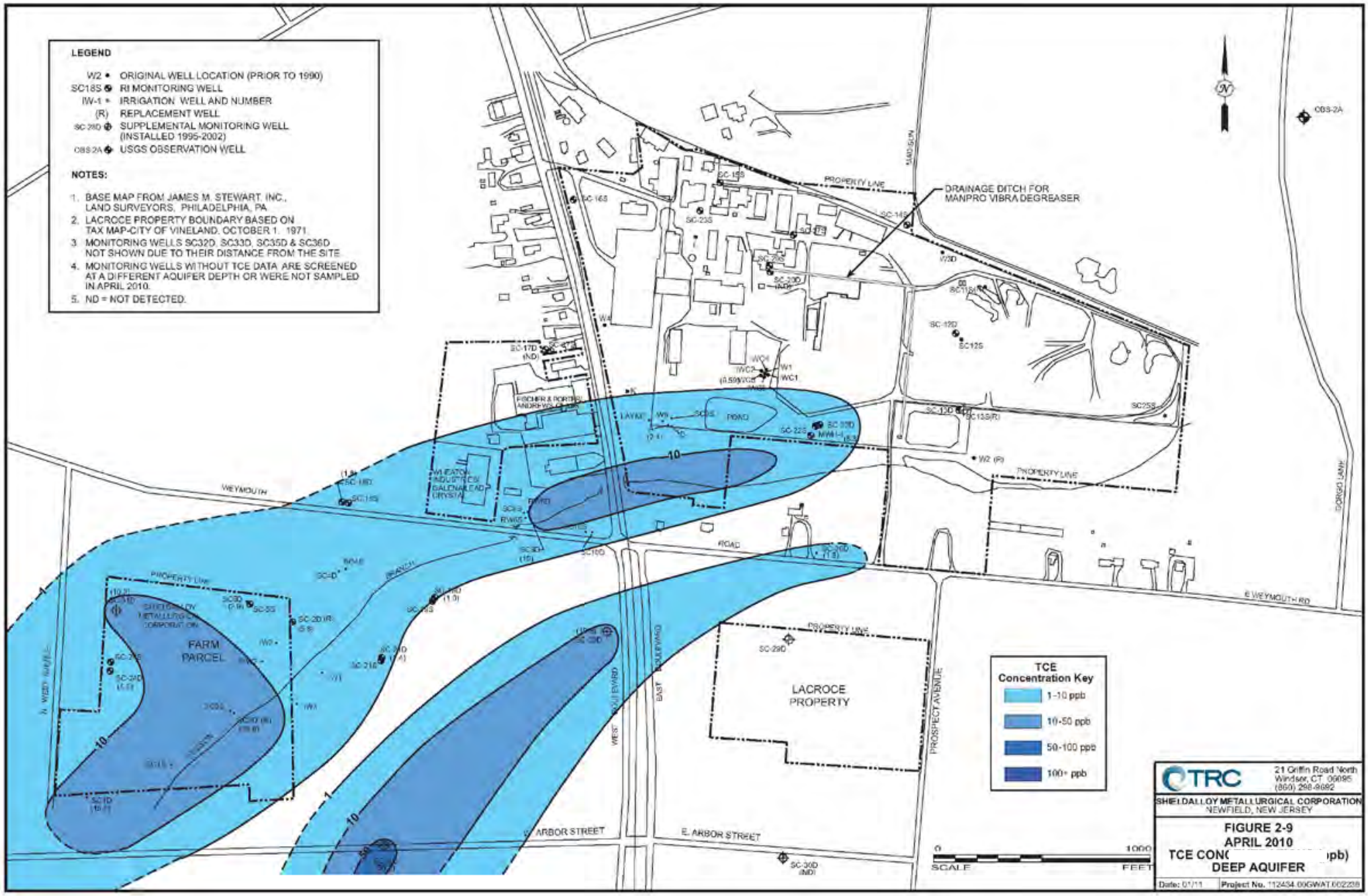
The TCE plume in the deep aquifer zone begins in the south/central portion of the Facility and continues towards and past the Farm Parcel. As depicted in Graphic 2-2 (next page) 2010 TCE concentrations in the deep aquifer zone ranged from non-detect to 20 µg/L from the Facility to the Farm Parcel. Downgradient of the Farm Parcel TCE concentrations were noted from non detect to 16 µg/L (VP-2). The TCE plume was broader downgradient of the Facility, as wide as 2,000 feet (including well SC34D on Arbor Avenue, at a concentration of 50 µg/L). The sandy nature of the aquifer would ordinarily yield a narrow, longer plume. Studies, discussed below, suggest that the broader nature of the TCE plume is indicative of off-site CVOC sources.

TRC's January 2011 Pre Design Investigation Report (*1. TRC, 2011*), approved by EPA February 2014, studied the TCE plume in detail, and accomplished offsite delineation to the NJDEP GWQS of 1 µg/L. The TCE plume (as defined as greater than or equal to 1 µg/L) in the deep aquifer zone extends from the Facility, southwest past the Farm Parcel, to a point (well SC-35D, where non-detect concentrations are observed), near the corner of Garden Road and Mill Road, approximately 2.5 miles from the Facility. The width of the TCE plume is approximately 1 mile. The 2011 report also concluded that TCE concentrations are the Farm Parcel are either stable or decreasing.

<u>Other CVOCs</u>

The 2011 Pre Design Investigation Report, approved by EPA March 14, 2014, also concluded that up to five non-SMC sources of chlorinated volatile organic compounds (CVOCs) exist, specifically immediately downgradient of the SMC Facility. Four out of five of these CVOC sources have documents PCE releases. It is noted that SMC never used PCE, and that PCE was never detected at the Facility. Therefore, PCE detections are indicative of non-SMC sources. NJDEP's GWQS for PCE is 1 µg/L. It is also noted that TCE is a daughter product of PCE breakdown. The fifth offsite source has documented TCE release. Therefore, detections of TCE downgradient of the offsite sources (from the Car Wash, southwesterly) is likely a product of offsite CVOC sources. It is also noted that SMC/TRC is not responsible for cleaning up, or further studying, contamination from other sources.

The 2011 Pre Design Investigation report noted PCE concentrations throughout the footprint of the TCE plume downgradient of the offsite sources, ranging from non-detect to 38 µg/L.



Graphic 2-2 Pre-Injection April 2010 TCE Concentrations (ppb) Deep Aquifer
NOTE: TCE Downgradient of the Facility are Caused by Non-SMC Sources

2.6 In Situ Remediation Pilot Program Progression

In situ remediation is recognized by USEPA and the scientific community as an effective strategy for the remediation of chromium and TCE in groundwater (*2. USEPA, 1997a/b*; *3. USEPA, 1999*; *4. USEPA, 2000a*; *5. USEPA, 2000b*; *6. IETEG, 2005*; *7. ITRC, 1998*).

The following sequence of *submissions*, regulatory responses, and TRC actions summarize the timeline progression of the ISR Pilot Program to date:

- 2007: Bench-Scale Treatability Studies
- January 2008 (TRC): *Permit-by-Rule In Situ Chemical Reduction Application Report* (*8. TRC, 2008*)
- January 2008 to June 2009: Technical, implementability, and cost evaluation and comments from NJDEP, USEPA, and US Army Corps of Engineers. (*9. NJDEP/USEPA/USACOE, 2008-2009*)
- July 2009 (TRC): *Amended Permit-by-Rule Application - In Situ Reduction Pilot Test Report* (*10. TRC, 2009*)
- November 1, 2009 (NJDEP/USEPA): Permit-by-Rule Approval Letter (*11. USEPA/NJDEP, 2009*)
    - November 2009 through June 2010 (TRC): Extensive bench-scale treatability study
    - April 2010 (TRC): Pilot Test - Focused buffered EVO injection at one Farm Parcel well (IW-2 Area)
    - September 2010 (TRC): Pilot Test - Focused CPS injection at one Facility well (TIW-1 Area)
- February 2011 (TRC): *In Situ Remediation Pilot Test Report and Facility Expanded In Situ Remediation Pilot Program (FEIPP) Workplan* (*12. TRC, 2011)*
- May 26, 2011 (USEPA/NJDEP): Final Approval Letter for Facility EIPP Workplan (PBR Equivalency) (*13. USEPA/NJDEP, 2011*)
- March 2011 through January 2012 (TRC): Implementation of Facility EIPP
- January 17, 2012: FEIPP Progress Meeting with USEPA/NJDEP
- January 19, 2012 (TRC): *Request for Time Extension of Existing FEIPP Equivalent PBR Letter* (*14. TRC, 2012*)
- January 25, 2012 (NJDEP): Facility Permit-by-Rule Equivalent Time Extension Approval Letter (*15. NJDEP, 2012*)
- February 2012 (TRC): *Facility Expanded In Situ Remediation Pilot Program Progress Report and Phase 2 Farm Parcel In Situ Remediation Pilot Study (FPIPS) Workplan* (*16. TRC, 2012*)

- April 16, 2012 (USEPA/NJDEP): Farm Parcel Permit-by-Rule Equivalency Approval Letter (*17. USEPA/NJDEP, 2012)*
- April 17, 2012 (USEPA/NJDEP): Final Approval Letter for FEIPP Progress Report and the Phase 2 Farm Parcel In Situ Remediation Pilot Study Workplan (*18. USEPA/NJDEP, 2012*)
- May 2012 through August 2012 (TRC): Implementation of Phase 2 Facility ISR Pilot Program – CPS polishing injections
- April 2012 through November 2012 (TRC): Implementation of Phase 2 Farm Parcel ISR Pilot Program
- January 16, 2013: OU1 ISR Pilot Program Progress Meeting with USEPA and NJDEP
- February 12, 2013 (TRC): *Request for Permit-By-Rule Equivalency Time Extension and Volume Expansion Letter* (*19. TRC, 2013*)
- February 13, 2013 (TRC): *Request to Turn Off the Car Wash Pumping Wells for MNA Assessment Letter* (*20. TRC, 2013*)
- February 14, 2013 (TRC): *Memorandum on EPA Procedural Assessment of MNA of Chromium in Groundwater at the Shieldalloy Corporation Superfund Site, Newfield, New Jersey* (*21. TRC, 2013*)
- March 6, 2013 (TRC): *OU1 In-Situ Remediation Pilot Program Progress Report* (*22. TRC, 2013*)
- March 26, 2013 (USEPA): Approval of the Operable unit (OU1) Phase 3 Farm Parcel Polishing Injections and Target Injection Program at the Car Wash Wells for the InSitu Remediaiton Pilot Program for the Shieldalloy Metallurgical Corp Site, Newfield, NJ Letter (*23. USEPA, 2013*)
- March 26, 2013 (USEPA): Approval to Turn Off the Car Wash Pumping Wells for the OU1 Remediation at the Shieldalloy Metallurgical Corporation Site, Newfield, NJ Letter (*24. USEPA, 2013*)
- April 1, 2013 (NJDEP): Discharge to Ground Water Permit-By-Rule Equivalent Extension Approval Letter (*25. NJDEP, 2013*)
- April 2, 2013 (USEPA/NJDEP): Comments on the Memorandum on EPA Procedural Assessment of MNA of Chromium in Groundwater at the Shieldalloy Corporation Superfund Site, Newfield, New Jersey Letter (*26. USEPA/NJDEP, 2013)*
- May 24, 2013 (TRC): *Memorandum on SMC MNA Model* (*27. TRC, 2013*)
- June Through July 2013 (TRC): Implementation of Phase 3 CPS Polishing Injections at Farm Parcel and Car Wash

- July 24, 2013 (TRC): *Memorandum SMC Site – MNA Monitoring Plan* (*28. TRC, 2013*)
- September 19, 2013 and October 7, 2013 (TRC): *Letters Requesting an Additional 6-month temporary inactivation of outfalls 001B and 004A in NJPDES Permit NJ0004103* (*29. TRC, 2013*)
- October 7, 2013 (NJDEP): Approval of Temporary Inactivation of Outfalls 001B (*30. NJDEP, 2013*)
- February 27, 2014: OU1 ISR Pilot Program Progress Meeting with USEPA and NJDEP
- March 20, 2014: OU1 ISR Pilot Program Progress Report and 2014 Workplan (*53. TRC, 2014)*

The treatability studies, pilot tests and pilot program completed to date included extensive evaluation of various amendments, amendment loading rates, amendment distribution, remediation efficacy, and treatment longevity/stability factors, each building upon the information learned in prior steps.

2.7 ISR – Technical Background

In-situ remediation has become widely recognized as a proven and effective strategy to address chromium and TCE in soil and ground water (*2. USEPA, 1997a/b*; *3. USEPA, 1999*; *4. USEPA, 2000a*; *5. USEPA, 2000b*; *6. IETEG, 2005*; *7. ITRC, 1998*). ISR can overcome the pump & treat limitations, specifically mass transfer rate limitations, and associated extensive costs and duration. Additionally, ISR is considered highly favorable in regards to "Green Remediation" principles.

The ISR techniques considered for the Site apply to both chromium and TCE and involve supplying reducing agents electron donors to induce reducing/anaerobic environments to reduce and precipitate chromium and degrade TCE to more innocuous compounds.

2.7.1 Chromium ISR Technical Background

It is useful to review the technical background for chromium ISR.

Basic Chemistry and Fate and Transport for Chromium

Chromium is a metal that can exist in oxidation (valence) states ranging from -2 to +6 but, in natural environments, it is commonly found as trivalent (+3) chromium [Cr(III)] or hexavalent (+6) chromium [Cr(VI)] (*31. USEPA, 2007*; *32. Palmer & Puls, 1994*). Trivalent chromium occurs naturally in many fresh vegetables, fruits, meat, grains, and yeast and is often added to vitamins as a dietary supplement. Cr(VI), which is most often produced by industrial processes, exists in oxidizing conditions and can move down through soil to underlying ground water (*31. USEPA, 2007*; *32. Palmer & Puls, 1994*). Cr(VI) is more mobile than Cr(III).

The fate and transport of chromium in natural environment is governed by the system pH, oxidation-reduction potential (ORP), and soil mineralogy and composition (*32. Palmer & Puls, 1994*; *6. IETEG, 2005*). Cr(VI) is a strong oxidant and is reduced to Cr(III) in the presence of reductants (electron donors) including ferrous iron, ferrous iron minerals (*e.g.,* ferrous hydroxides), and soil organic matter. In addition, ferrous iron and ferrous oxyhydroxide (*6. IETEG, 2005*; *32. Palmer & Puls, 1994*) surfaces have a substantial capacity for adsorption of chromium.

<u>Basic ISR Processes for Chromium</u>

The goal of *ISR* of chromium is to reduce the soluble, and mobile Cr(VI) to the less toxic and less mobile Cr(III), which forms relatively insoluble precipitates (chromium hydroxides or chromium-metal complexes). The combined processes of shifting the Redox state to a reducing environment and the precipitation of chromium are referred to as in situ reduction or more broadly in situ geochemical fixation. The final outcome is the removal and transference of Cr(VI) from groundwater to insoluble Cr(III) compounds in soil. This process is generally stable under a wide range of geochemical conditions. The only known condition that may result in the reversal of this process and re-oxidation of Cr(III) to Cr(VI) is the presence of manganese oxides at elevated concentrations in a strongly oxidized environment. These negative conditions do not exist at the SMC Site.

Both *biotic* (biologically-mediated) and *abiotic* (chemical) reducing processes are used to remediate chromium in situ (*32. Palmer & Puls, 1994*; *2. USEPA, 1997a/b*; *3. USEPA, 1999*; *5. USEPA, 2000b*; *31. USEPA, 2007*; *6. IETEG, 2005; 33. Freedman and Verce, 2003; 34. Jung and Lee, 2005; 35. Kolstad et al., 2004; 36. Loeper et al., 2002; 37. Murt et al., 2010a&b; 38. Puls, 2000; 39. Rouse and Thomasser, 2004; 40. Storch et al., 2003; 41. Tremain and Keel, 2000; 42. USDOE, 2006; 43. Wazne et al., 2007; 44. Zawislanski et al., 2004*). *Biotic* processes rely on organic substrates (lactate, poly-lactate, EVO, and molasses) to sustain microbial activities and induce reducing conditions, and ultimately reduce Cr(VI). *Abiotic* processes involve the addition of a chemical amendment to induce the required reducing conditions. The most common chemical amendments are sulfide products (*e.g.,* CPS, ferrous sulfide and sodium dithionite). Amendments are selected to provide maximum results, based on site-specific considerations.

This process of reducing Cr(VI) to Cr(III) is stable and irreversible, based on published studies and through observations at the SMC site.

2.7.2 TCE ISR Technical Background

It is useful to review the technical background for TCE ISR.

<u>Basic Chemistry and Fate and Transport for TCE</u>

TCE is a CVOC that is used for dry cleaning and industrial cleaning and degreasing operations. TCE has low viscosity and density that is greater than water. It is slightly soluble in water and is chemically stable under typical aerobic conditions. TCE can move down through soil to underlying groundwater. The fate and transport of TCE in the groundwater is governed by advection, dispersion, diffusion, volatilization, adsorption, biodegradation, and chemical reactions.

The higher density than water typically results in plumes that migrate to deeper zones of the aquifer, which is commonly known as a diving plume. This is the case at SMC where the remaining TCE plume is at depth with approximately 25 to 85 feet of groundwater without TCE impacts above it. This "clean water lens" prevents volatilization and vapor intrusion.

It is noted that, because downgradient TCE does not exist in the shallow aquifer, that this TCE does not present concerns or risks for vapor intrusion into buildings.

Basic ISR Processes for TCE

Mechanisms facilitating ISR of TCE in groundwater primarily include volatilization, sorption, dispersion, and biodegradation (*45. EPA, 1998*). Volatilization and sorption are mass transfer processes. In volatilization, the mass of a volatile compound in groundwater is reduced through the transfer of the compound from an aqueous phase into a vapor phase. This process takes place across the water table interface. Based upon a review of groundwater analytical data, TCE exists primarily in the deep aquifer at the Farm Parcel and downgradient locations. On this basis, volatilization does not appear to be a significant process for TCE.

Similar to volatilization, sorption is a mass transfer process whereby a volatile organic compound (e.g., TCE) partitions from a dissolved aqueous phase onto organic carbon that is present in the aquifer soils. Sorption is often expressed in terms of a linear isotherm model (i.e., Freundlich Isotherm) that is based upon the following equation (*46. EPA, 1989*):

$$K_d = C_s/C_w = K_{oc}*f_{oc}$$

Where:
- K_d = distribution coefficient (volume/mass);
- C_s = concentration of constituent of interest (mass/mass);
- C_w = concentration of constituent of interest in groundwater (mass/volume);
- K_{oc} = organic carbon partitioning coefficient (volume/mass) ;
- f_{oc} = fraction of organic carbon (dimensionless).

Dispersion neither destroys nor reduces contaminant mass in the aqueous phase. Instead, dispersion acts as an attenuation mechanism by reducing concentrations of a constituent of interest in groundwater through diffusion and mechanical mixing that occurs as a result of variations in groundwater velocity at a macroscopic level.

Biodegradation is considered to be one of the more important mechanisms of in situ attenuation of organic compounds such as TCE, since this process involves a reduction in contaminant mass. Note that the ISR Pilot Program work performed at the Site for TCE in 2011 focused on fostering biodegradation. Biodegradation of TCE can occur under anaerobic, anoxic, or aerobic conditions (*47. Lawrence, 2006*). Depending upon the geochemical conditions in the aquifer, TCE may be used as an electron acceptor, electron donor or it can be co-metabolized. The following paragraphs discuss these biodegradation mechanisms as described by Lawrence (*47. Lawrence, 2006*).

Electron Acceptor Reactions (Reductive Dechlorination)

TCE is typically degraded under anaerobic and reducing conditions (i.e., low dissolved oxygen in the presence of a suitable electron donor with oxidation-reduction potentials (ORPs) typically <50 millivolts [mV]). It is noted that the ISR Pilot Program has effectively lowered the ORP to less than the 50 mV target (in fact has decreased the ORP to negative numbers), which is conducive to fostering TCE biodegradation. This process is referred to as reductive dechlorination and is catalyzed by microorganisms in which a chlorine atom is removed and replaced with a hydrogen atom. The sequential biodegradation of TCE can be summarized as follows:

TCE → 1,2-DCE or 1,1-DCE → Vinyl Chloride → Ethene → Ethane

It should be noted that this sequence of biodegradation may be interrupted under anoxic or anaerobic conditions by another process (i.e., anaerobic direct metabolism) where daughter products may be directly metabolized by microorganisms to carbon dioxide (CO_2).

Reductive dechlorination is mediated by electron acceptors which can include nitrate, ferric iron (Fe^{+2}), sulfate, and/or CO_2 (*45. EPA, 1998*). As each electron acceptor is utilized, it is converted to its reduced form (e.g., nitrate to nitrite, ferric iron to ferrous iron, sulfate to sulfide, and CO_2 to methane). Thus, a reduction in the electron acceptor concentrations along a flow path and/or the presence or accumulation of the corresponding reduced species can also indicate that reductive dechlorination is occurring.

Cometabolism

Cometabolism describes the dechlorination of TCE catalyzed by an enzyme or co-factor produced by the bacteria for cellular metabolism. During cometabolism, the TCE is indirectly transformed by bacteria as they use another substrate (e.g., methane) to meet their energy requirements. Therefore, other sources of carbon and energy are needed to maintain bacterial activity. Cometabolic degradation of TCE under aerobic conditions tends to be limited to low concentrations in the µg/L range (*47. Lawrence 2006*) because higher concentrations in the mg/L range inhibit microbes that facilitate cometabolic biodegradation reactions. On this basis, reductions in naturally occurring or anthropogenic sources of organic carbon along a flow path accompanied by a reduction in TCE could be evidence of cometabolic biodegradation of TCE.

The ISR of TCE has been extensively studied. The efficacy of TCE ISR must be based on site-specific studies and considerations.

3.0 ISR PILOT PROGRAM EVALUATION

As discussed in Section 1, the ISR pilot program has been progressive and aggressive. The program started with white paper studies and bottle studies in 2007, and evolved to more extensive bench scale tests, trying a variety of injection materials and combinations through 2009. These early study results indicated that CPS would be an effective amendment to treat the primary contaminant, chromium. Bench scale testing results also showed that EVO would be an effective amendment for the secondary contaminant, TCE.

Following the April 2010 execution of the Administrative Order on Consent (AOC), the in situ pilot program goals were established to validate laboratory studies with progressively larger scale field injections in order to validate the in situ technology, reduce concentrations, and to study and foster natural attenuation. "Single well" CPS injection tests were conducted in 2010. 2011, 2012, and 2013 have included broad scale and iterative pilot injections. This process is designed to dramatically shift the subsurface environment to both reduce concentrations, and foster longer-term concentration reduction via natural attenuation.

To date, approximately 75 tanker trucks worth of CPS have been suitably injected (yielding very good results, discussed below) into a well network including approximately 100 injection wells, and 100 monitoring wells over a ½ mile plume. Additionally, EVO injection at a grid of temporary well points has reduced TCE concentrations at the key well (SC-20S) from 207 µg/L to non-detect.

The AOC Task IV, paragraph G requires that a pilot program undergo appropriate evaluation, to determine if the studied remedial technology is effective, implementable, and cost effective, and, in general, if the study achieved predicted outcomes. The ISR Pilot Program Evaluation includes the following components:

- Summary of chromium concentration reductions;
- Chromium results permanence evaluation;
- Summary of chromium MNA evaluation;
- Summary of TCE concentration reduction;
- Summary of TCE MNA evaluation;
- ISR Pilot Program effectiveness, implementability, and cost; and
- ISR Pilot program conclusions.

These components are further discussed in the following subsections.

3.1 Summary of Chromium Concentration Reductions

The results of the in situ remediation pilot Program indicate that CPS polishing injections resulted in accelerating the reduction of chromium concentrations at the Facility, Farm Parcel and the Car Wash, as discussed in the subsections below.

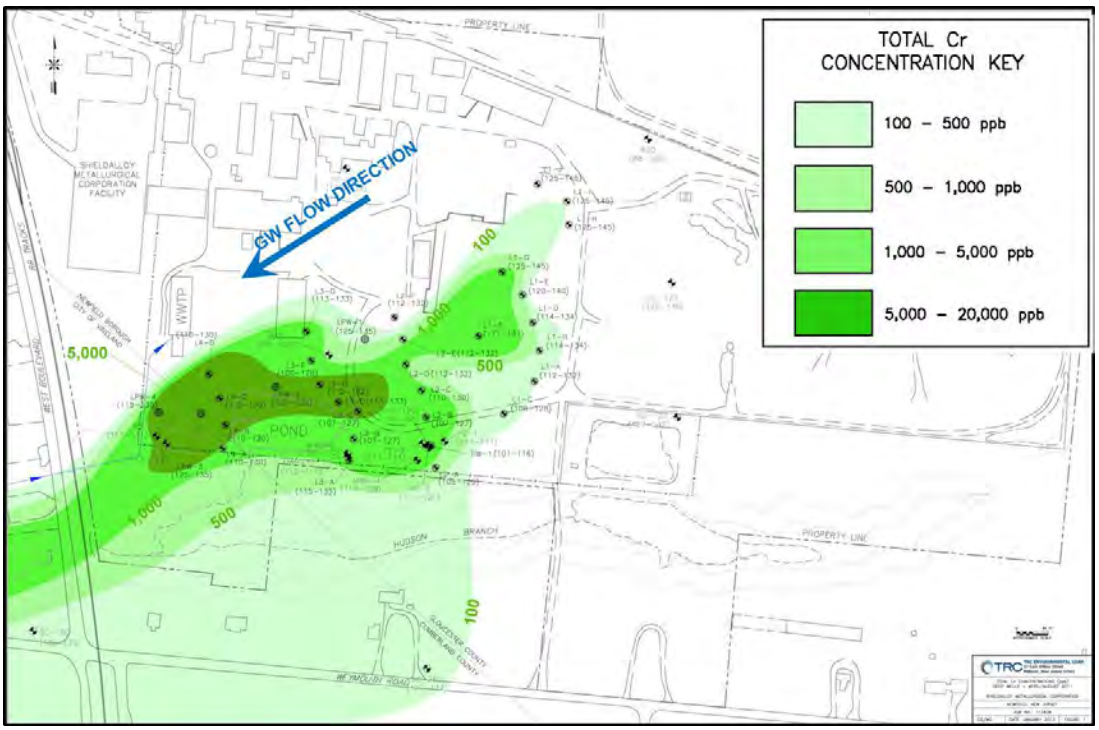
3.1.1 Facility ISR Pilot Program Conclusions

ISR Pilot Program included significant Facility CPS injections in 2011 and 2012. Because ISR Pilot Programs objectives had been met, no CPS injections were performed at the Facility in 2013.

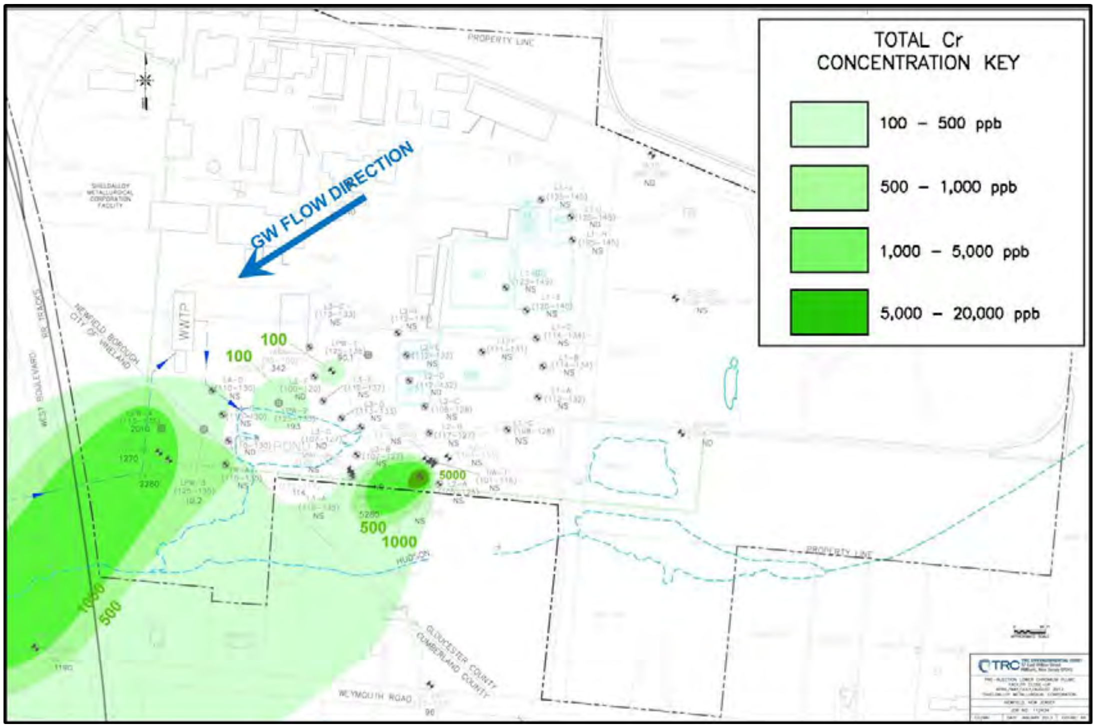
The 2013 ISR Progress Report (TRC, 2013) summarized the Facility results as follows:

- 95-99% reduction of average Cr & Cr(VI) concentrations in Facility wells [from 4,490 to 140 µg/L for Cr(total) and from 2,130 to 13 µg/L for Cr(VI)]; and
- Many Facility wells observed 98%-100% reduction.

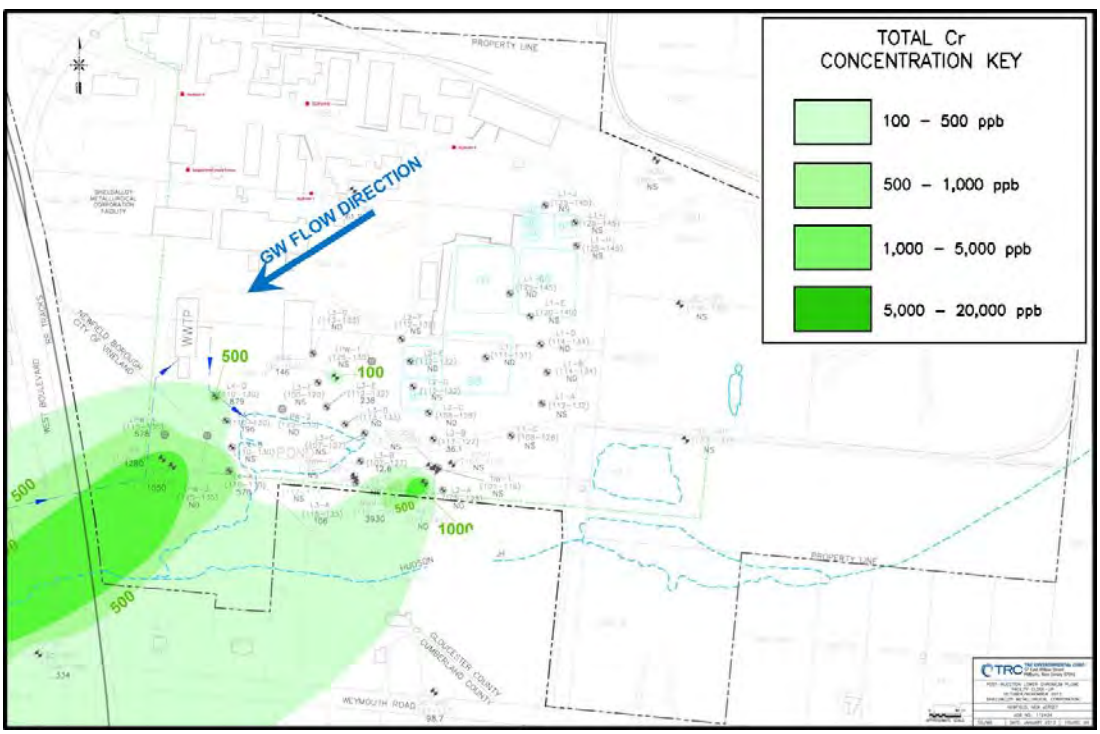
The chromium isopleths for pre-injection (April-August 2011), post-initial injection (October 2011), and post-polishing injection (October-November 2012) are shown in Graphs 3-1 through 3-3 below:



Graph 3-1: Total Chromium at Facility Pre-Injection (April-Aug 2011)

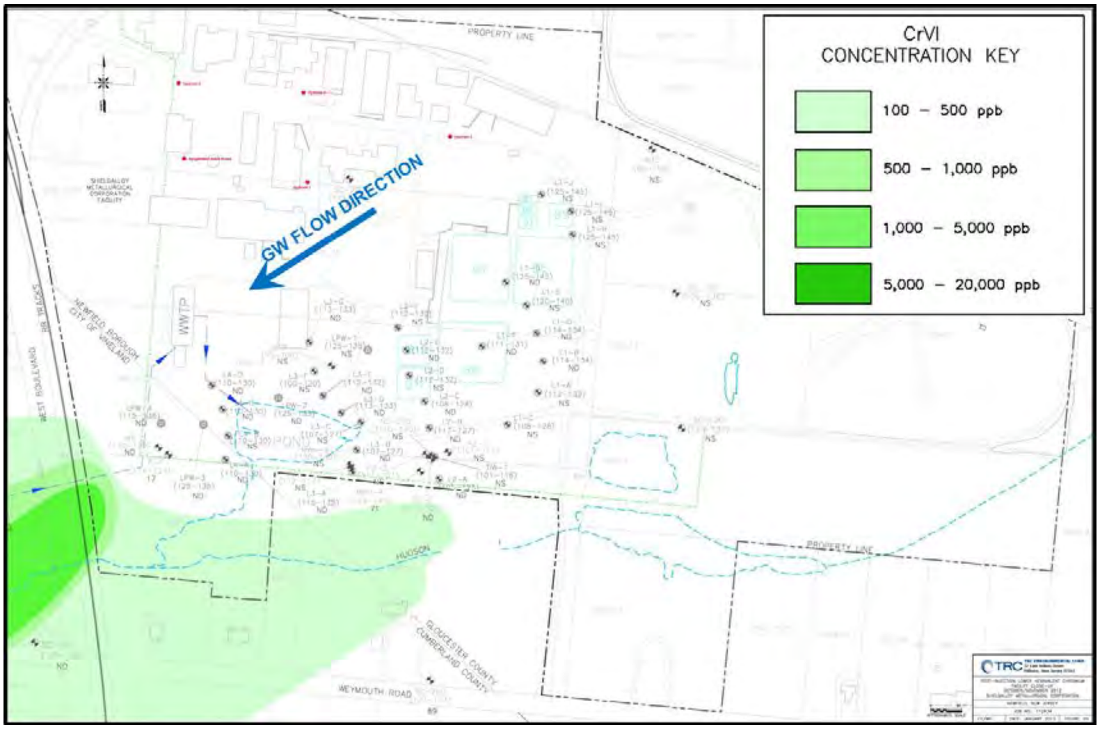


Graph 3-2: Total Chromium at Facility Post-Initial-Injection (Oct 2011)



Graph 3-3: Total Chromium at Facility Post-Polishing-Injection (Oct/Nov 2012)

Review of the isopleths shows that the chromium plume is dramatically reduced after both the initial, and the polishing injection. The footprint of the plume is dramatically decreased. In fact, many Facility wells are "clean" with concentrations below the GWQS of 70 µg/L. Furthermore, the lower zone, hexavalent chromium plume at the post-polishing injection (shown below) demonstrates the expansion and spreading of the CPS treatment front to areas downgradient of the Facility.



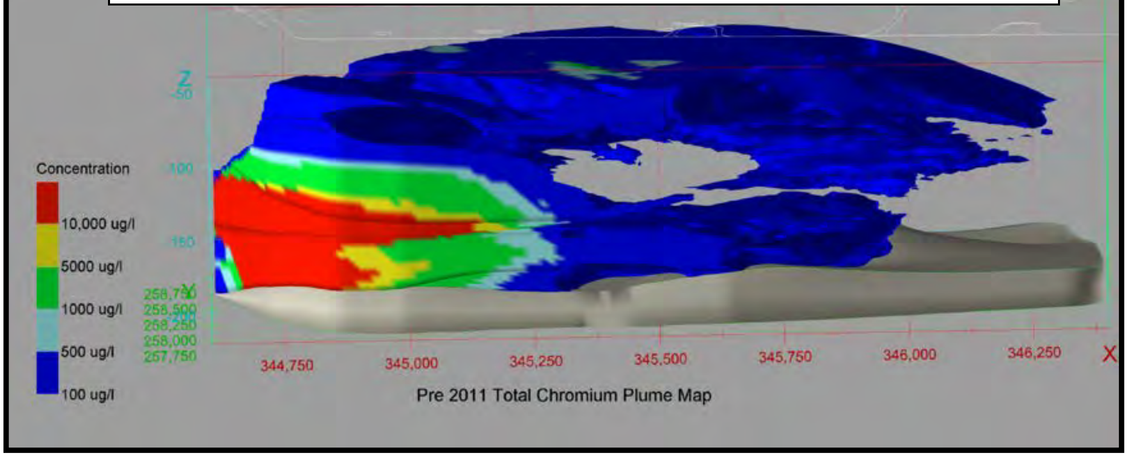
Graph 3-4: Hexavalent Chromium at Facility Post-Polishing-Injection (2013)

The isopleths shown above are for the lower aquifer zone. In order to give a three-dimensional (3-D) perspective, that incorporates all Facility wells, 3-D visualizations of the pre-injection, post-initial-injection, and post-polishing-injections are shown below (Graphs 3-5, 3-6, and 3-7).

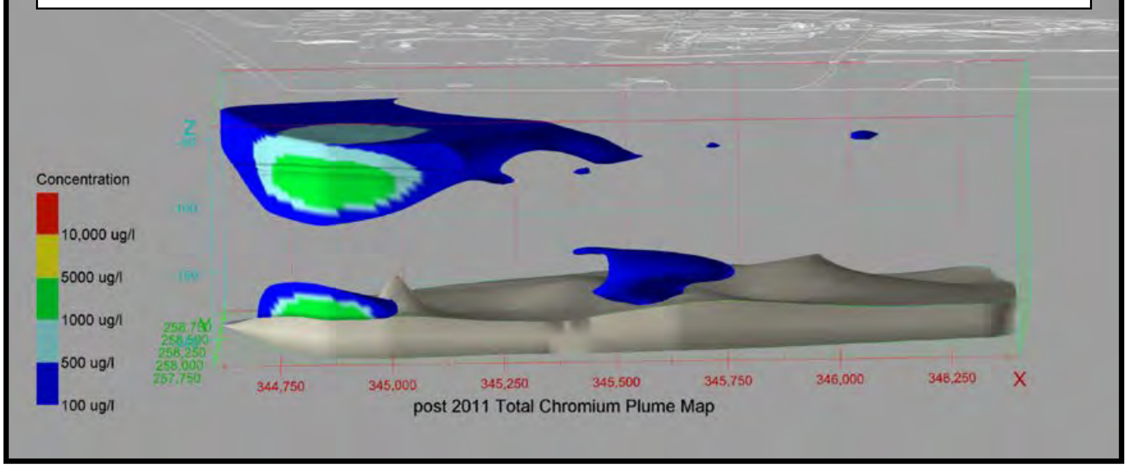
These 3-D views show that the extents of the plume (defined as the concentrations meeting regulatory criteria) have been greatly reduced. In fact, calculations show that the ISR Pilot Program has reduced the plume footprint by 60 times. Further, the very high concentrations, depicted by the red and yellow shading, are gone.

The chromium reductions at the Facility have been remarkable, and exceed expectations.

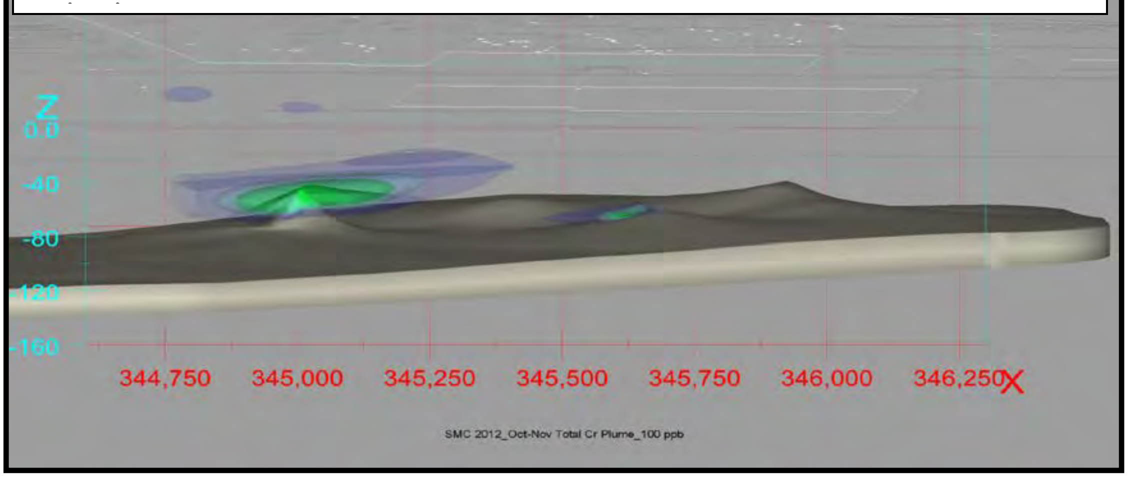
Graph 3-5: 3-D View of Total Cr Plume at Facility – Pre Injection



Graph 3-6: 3-D View of Total Cr Plume at Facility – Post Initial Injection



Graph 3-7: 3-D View of Total Cr Plume at Facility – Post Polishing Injection



(*) *The grayish feature at the bottom is the aquitard (i.e., Kirkwood Clay)*

3.1.2 Car Wash and Farm Parcel ISR Pilot Program Conclusions

The effectiveness of CPS treatment at the Car Wash is demonstrated by:

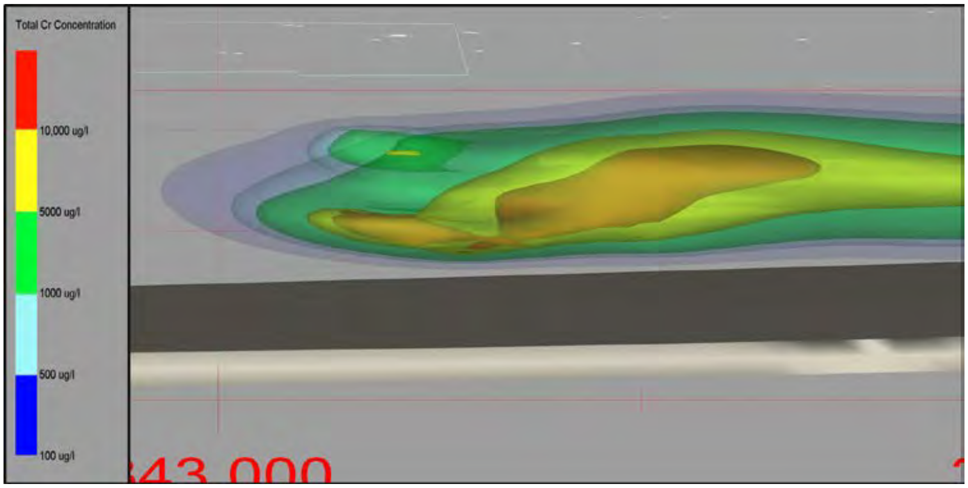
- >80% reduction of Total Cr concentrations in wells within or near the treatment zone (decreased from ~1,144 µg/L April 2012 to ~196 µg/L October 2013). 98%-100% reduction of Cr concentrations at some wells;
- >90% reduction of Cr(VI) concentrations in wells within or near the treatment zone (decreased from an average 977 µg/L April 2012 to 76 µg/L October 2013);
- 98%-100% reduction of Cr(VI) concentrations at some wells;
- The concentration reductions at the Car Wash have been substantial, and are sufficient to have met program objectives. No further polishing injections are proposed for the Car Wash area.

The Farm Parcel results indicate remediation progress as summarized below:

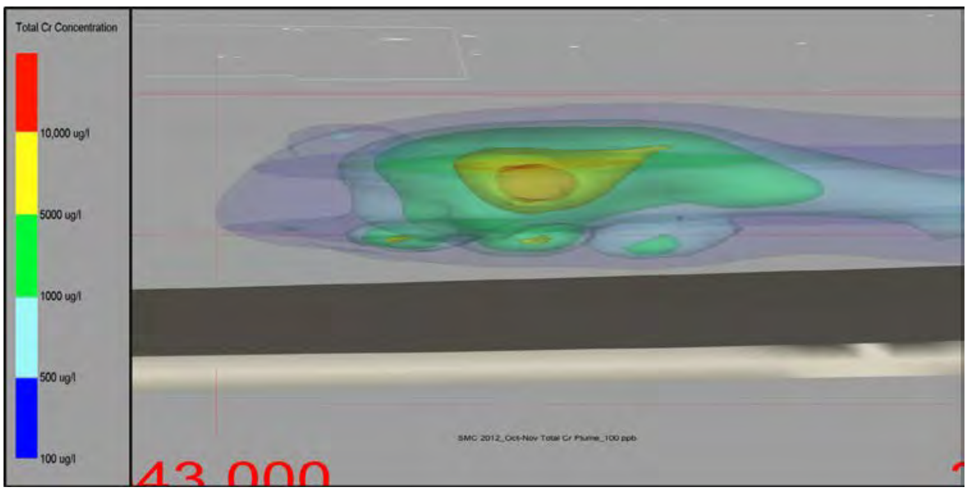
- 79% reduction of Total Cr concentrations in wells within or near the treatment zone (decreased from ~5,024 µg/L April 2012 to ~1,066 µg/L October 2013). It is noted that, out of approximately 53 injection wells and 50 monitoring wells at the Farm Parcel, that only a limited number of wells (~6 wells) currently have chromium concentrations higher than the action target (1,250 µg/L). These half-dozen wells skew the average reduction. In other words, when these 6 wells are addressed, the total percentage reduction is expected to go from 80% to >90% ;
- 98%-100% reduction of Cr concentrations at many wells;
- 93% reduction of Cr(VI) concentrations in wells within or near the treatment zone (decreased from 4,909 µg/L April-August 2012 to 347 µg/L October 2013); and
- There remain localized, elevated concentrations that would benefit (i.e., cleanup time will be reduced) from additional polishing injections at the Farm Parcel.

TRC proposes targeted injections to complete the CPS injections and treatment at the Farm Parcel in 2014 (Section 4).

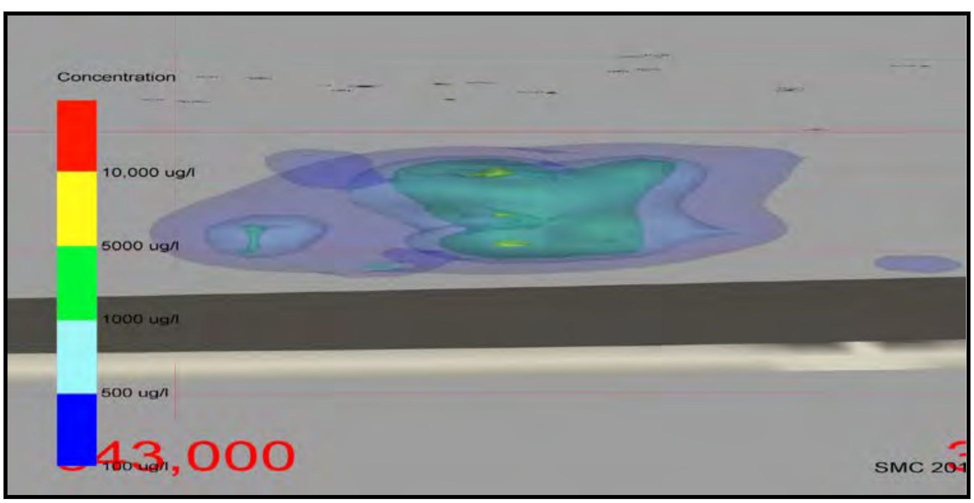
Finally, pre-injection and post-injection chromium results for 2013 injections were compiled into 3-D views for the Farm Parcel section of the plume as shown below in Graphs 3-8 through 3-10. The view is configured such that the reader is looking from the Southwestern area near RIW-2 (front left side of image) and upgradient in a North-Northeasterly direction extending to approximately Weymouth Road (back right side of image). The grayish feature at the bottom is the aquitard (*i.e.,* Kirkwood Clay). As is evidenced in these graphs, CPS injection has resulted in decreasing the highest concentrations (red, orange, yellow gradations) and shrinking the core of the plume. Mass reduction is expected to continue as CPS spreads and reacts.



Graph 3-8: 3-D View of Cr Plume at Farm Parcel-Pre Injection (April-August 2012)



Graph 3-9: 3-D View of Cr Plume at Farm Parcel - Post-Injection (October 2012)



Graph 3-10: 3-D View of Cr Plume at Farm Parcel - Post Injection (October 2013)

These 3-D images provide a helpful visual which demonstrates the significant mass reduction that has occurred at the Farm Parcel due to the ISR pilot programs thus far.

Farm Parcel results indicate, however, that there is a localized area (at and just downgradient of injection row 7) that has not yet achieved the desired chromium concentration reduction. The soil grain size in this localized area appears to be somewhat smaller than in other areas, which has limited the spreading of CPS. It has also been determined that the installation of a few additional injection wells, and targeted 2014 injections would overcome these geologic limitations, to better achieve ISR Pilot Program goals.

3.2 Chromium Concentration Reduction Stability Evaluation

Early studies predicted that the chromium concentration reductions created by CPS injections would be permanent (stable and irreversible). In order to confirm this finding, TRC evaluated a variety of site-specific data, including geochemical data and chromium concentrations over time, as discussed in the subsections below.

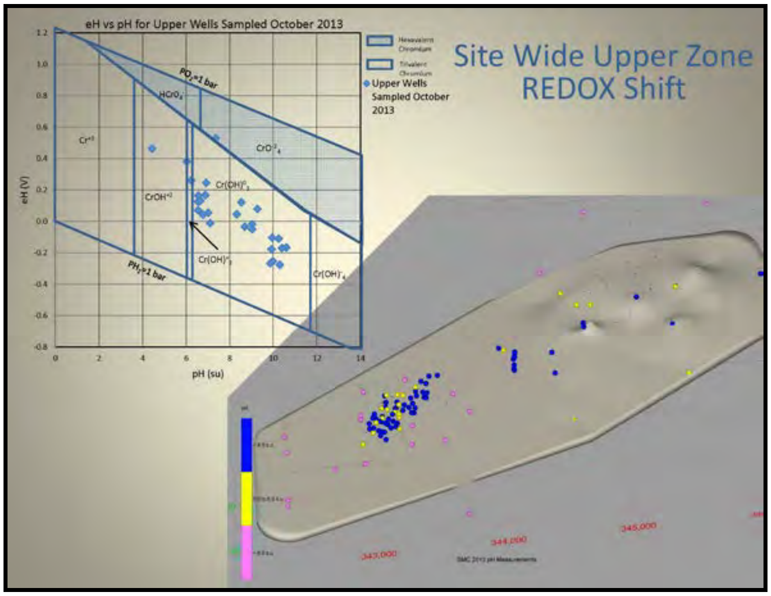
3.2.1 Geochemistry

In-well and low-flow purging geochemical measurements were collected routinely to monitor treatment progress. As discussed in Section 1, the primary geochemical data that affects ISR is DO, pH, and redox.

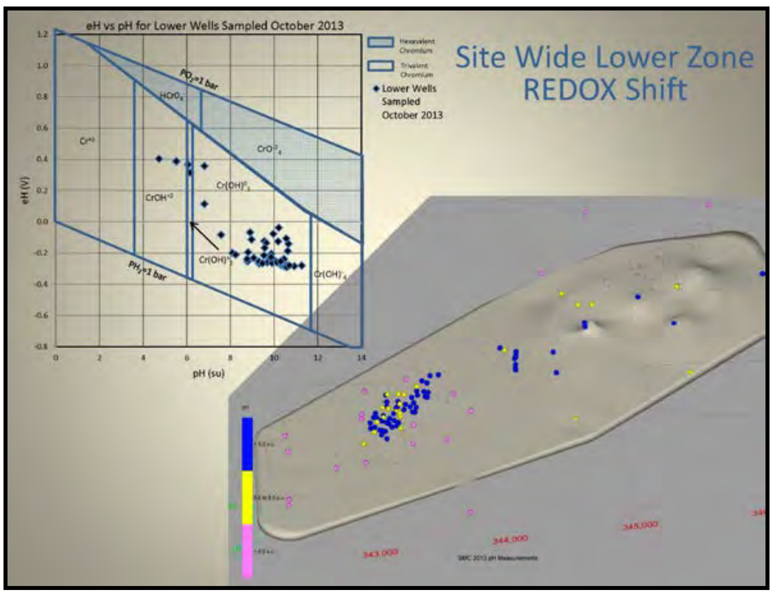
<u>pH and Redox</u>

Data indicate that, for the majority of the treatment zone wells, the ORP has shifted or is shifting toward reducing conditions, which is favorable for chromium reduction and precipitation.

Considering pH and redox together is helpful for evaluating geochemical conditions relative to ISR performance. Graphs 3-11 and 3-12 depict the October 2013 Redox conditions in the eH-pH plots and pH distribution for the upper and lower zone wells, respectively. The eH-pH plots indicate that the majority of the redox conditions for the site are favorable for the reduced, trivalent form of chromium [Cr(III)] in both upper and lower zones. It is readily known in the literature and demonstrated at this site that under natural conditions the reduction of Cr(VI) to Cr(III) is irreversible and stable in this form.



Graph 3-11: Upper Zone Redox Conditions - October 2013



Graph 3-12: Lower Zone Redox Conditions - October 2013

The pH distribution maps display a three-dimensional, color-coded representation of pH throughout the plume where pink spheres represent pH values less than 6 s.u., yellow spheres represent neutral pH conditions between 6 and 8 s.u., and blue spheres represent pH values greater than 8. As is evidenced by these graphs, the treated areas (*i.e.*, many of the interior locations near the center of the plume) have increased pH values in the neutral and alkaline range, which is conducive and appropriate for insoluble chromium.

Dissolved Oxygen

The dissolved oxygen (DO) within the EVO-treatment area near SC-20S is depleted indicating anaerobic and reducing conditions were created to enhance reductive dechlorination. Furthermore, within the CPS treatment zones DO is depleted which could have beneficial effects on MNA for the low levels of TCE present within some of these zones.

Accordingly, data show that the ISR Pilot Program has induced amenable geochemical conditions and favorable and stable changes.

3.2.2 Facility Chromium Concentrations Trend Analysis

The Facility provides a good basis for analysis of stability, because the Facility did not receive CPS injections in 2013. Accordingly, analysis of data year over year (2012 to 2013) will help indicate chromium trends, post injection.

Chromium concentrations (both hexavalent and total) from Oct 2012 were compared to concentrations from Oct 2013, below:

Well ID	**Hexavalent Chromium (µg/L)**			**Total Chromium (µg/L)**			**Comment**
	Pre ISR	**Oct-12**	**Oct-13**	**Pre ISR**	**Oct-12**	**Oct-13**	
Wells essentially unaffected by ISR (kept safe)							
SC-13S	ND	30	33	ND	ND	ND	Below regulatory levels throughout process
SC-14S	15	240	ND	27	259	ND	Below regulatory level before and currently
Wells nearly completed ISR Treatment							
LPW-4	20,200	ND	ND	18,100	578	261	From very high, to approaching regulatory levels
IWC5	120	--	ND	279	--	68	Treatment to below regulatory levels
Layne	630	ND	ND	897	10.1	ND	Treatment to below regulatory levels
Wells with highest chromium onsite, still undergoing active ISR (over 1 year after injections)							
W9	3,000	ND	ND	3,570	1,280	1,630	First step of treatment, conversion from Cr(VI) to Cr(III), completed. Active remediation of total chromium ongoing (concentrations of total chromium should decrease upon aquifer stabilization)
MWH-4	98	711	ND	1,840	3,930	1,980	First step of treatment, conversion from Cr(VI) to Cr(III), completed. Active remediation of total chromium ongoing (concentrations of total chromium should decrease upon aquifer stabilization)

This analysis indicates the following:

- Wells that had low chromium concentrations before injections continue to have low chromium concentrations, indicating that no adverse effects due to ISR;
- The first step of the chemical process, the conversion of hexavalent chromium to the less toxic and less mobile trivalent chromium, is occurring (in some cases is complete, in other cases is undergoing continued active transformation);
  - the concentrations reduction of total chromium concentrations follows the hexavalent-to-trivalent transformation;
  - hexavalent concentrations have not rebounded (indicating that the transformation is irreversible);
- A key well that had very high chromium concentrations (greater than 18,000 µg/L) was dramatically reduced immediately following injections, and continues to decrease;
- Other wells in the treatment zone show continuing chromium concentration reductions.

This indicates that the reaction is irreversible, as also documented during the treatability studies. Total chromium concentrations have also remained either stable or decreasing. This indicates that the chromium reduction/precipitation is stable and irreversible.

3.3 Longevity of CPS Activity Assessment

As discussed in Section 1, the overall process of ISR, following injections, transitions from the more active stages, where amendments are present and continue to react to decrease concentrations, to the less-active stage, where natural attenuation becomes more prevalent. This process is a continuum (not a step-like) because the subsurface processes evolve over time.

In order to assess the timeliness of the ISR Pilot Program relative to the more-active to less-active spectrum, TRC revisits the geochemical parameters discussed in Section 2. Specifically, the ISR Pilot Program has demonstrated that CPS continues to be present when pH is higher, and when ORP is lower (even negative). In terms of the depiction in graphs 3-11 and 3-12, these conditions exist where the “blue dots” are shown. As indicated in those graphs, CPS remains present at the Facility as of October 2013 (even though the last polishing CPS injection stopped in September of 2012, a year earlier). This indicates that the more active stage, while CPS is still present and active, exists at least one year after injections.

TRC performed modeling to forecast the time that CPS will persist. TRC utilized BIOSCREEN, an EPA-supported analytical solute transport model, designed to simulate advection, dispersion, adsorption, and decay (biotic or abiotic), to estimate the residence time for sulfide, the active component of CPS. TRC used site-specific input parameters, based on extensive laboratory and field testing, including hydraulic conductivity, CPS mass and volume, dispersion parameters, retardation factor, and first order decay coefficient (sulfide half-life). Simulations were run for both the upper zone, and lower zone, because each zone has different hydrogeologic properties. Also, TRC modeled both the Facility scenario and the Farm Parcel scenario, to reflect the differing site conditions, and provide a reasonable range of estimates. For purposes of estimating the residence (reactivity) time of sulfide a "threshold" concentration of 1 mg/L was assumed to be the concentration at which sulfide remains active in the upper zone and 10 mg/L in the lower zone (due to the more competing processes and lower permeability). This threshold concentration, which was based on observations made during the column treatability studies, is nominal due to the variability and uncertainty in subsurface hydrogeological and geochemical conditions.

Modeling results predicted the nominal sulfide (CPS) residence time to be 5 years in the upper aquifer zone 20 to 35 years in the lower zone. The nominal sulfide residence time in the lower zone is longer due to the larger CPS dosage and smaller hydraulic conductivity in the lower zone. Monitoring can be performed to better assess the actual CPS residence time at the site.

Based on the modeling, included in Appendix A, CPS may remain active for 5 to 10 years for the upper zone and 20 to 35 years for the lower zone. It is noted that pumping groundwater while conditions are in the more active stage would be detrimental and counterproductive, because it would remove the valuable CPS from the aquifer.

Similarly, the geochemical conditions (*i.e.*, low to negative ORP levels, and low DO levels, pH levels between 6-8 s.u., and presence of dissolved/ferrous iron) that are favorable for chromium ISR, are also favorable for TCE ISR.

3.4 Chromium MNA

TRC has been performing systematic and progressive MNA evaluations at the Site. During 2013, TRC completed a chromium MNA evaluation based on EPA's 4-criteria protocol, as requested (TRC, February 2013). That evaluation concluded that chromium MNA is viable for the Site, and set some initial target MNA concentrations goals (*i.e.*, target "threshold" concentrations at which the Farm Parcel sentinel wells will remain compliant via MNA mechanisms).

Regulatory input indicated a desire to perform additional MNA sampling under "non-pumping" conditions, and to perform more detailed MNA modeling. Following that direction, the pumping wells (Car Wash) wells were turned off, deactivating the pump and treat system in March 2013. TRC submitted an MNA monitoring plan, and has been collecting MNA data quarterly since April 2013. The data from July 2013 and October 2013 are included herein. Further analysis of the data will be submitted under separate cover after the more-recent data is available and compiled.

TRC also prepared an MNA model (TRC, May 2013). The EPA's BIOSCREEN modeling program was used to simulate advective-reactive transport, and natural attenuation of dissolved chromium in groundwater via sorption and chemical reduction/precipitation (decay). The model input included site specific chromium concentration and mass at source locations, and measured hydrogeologic properties and retardation factors. The model incorporated multiple conservative assumptions (*e.g.*, taking highest well concentrations as base case, and assuming that injections would not further reduce concentrations, among others), to provide safe and conservative results.

The model concluded that MNA is viable and appropriate for the Site, and would keep sentinel wells (specific wells downgradient of the Farm Parcel) below regulatory standards over time. The model also calculated target "threshold" concentrations at the Farm Parcel, at which MNA is viable. Both average concentrations, and localized high allowable threshold concentrations, were developed, each for the lower and upper zones. The upper zone allowable average is 750 µg/L, and localized high of 1,000 µg/L total chromium. The lower zone allowable average is 1,250 µg/L, and the localized high of 2,700 µg/L total chromium.

3.5 Projected Time to Achieve Chromium Regulatory Standards

The time to achieve cleanup goals is a fundamental factor in evaluating a remedial approach. It is appropriate to compare the time to cleanup for ISR (the focus of the Pilot Program) versus pump and treat (the technology specified in the ROD).

TRC performed modeling to project the time to achieve regulatory standards (NJDEP GWQS of 70 µg/L). The EPA's BIOSCREEN modeling program was used to predict the remedial timeframe (RTF) for ISR followed by MNA and the EPA's Batch Flushing Model (EPA, 1988) developed by Gelhar and Wilson (1974) was used to predict the RTF for pump & treat. The modeling results, included in Appendix B, indicate that pump and treat would achieve NJDEP GWQS for chromium in approximately 440 to 600 years. Comparatively, the modeling results indicate that ISR as implemented through 2014 followed by MNA, would achieve GWQS in approximately 120 to 310 years. The time to cleanup for ISR for Chromium can be revisited (possibly improved) after the 2014 injections are completed.

Compared to pump and treat, the ISR (followed by MNA) would achieve cleanup goals many times faster than pump and treat.

3.6 Summary of TCE Concentration Reductions

The ISR Pilot Program injections of EVO via a grid of temporary points into the shallow groundwater "source" area of TCE at the Facility successfully reduced TCE concentrations from 207 µg/L (2010) to non-detect (2012 and 2013). The non-detect concentrations over two years indicates that the concentration reduction is permanent (as expected).

3.7 Summary of TCE MNA

The 2011 OU1 Pre Design RI, approved by the EPA in March 2014, studied TCE MNA in detail, particularly in the area downgradient of the Farm Parcel. The IV-Tier study found that TCE concentrations in this area are stable or decreasing, which indicates that MNA is viable and appropriate for the Site. The studies found that biodegradation, sorption, and dispersion are the primary processes for TCE MNA. Dissolved oxygen concentrations at these areas were found to be anoxic, which is favorable for TCE biodegradation. Low redox potential (<50 mv) is favorable to TCE MNA. Prior to ISR pilot injections, were less than 50 mv. Since Farm Parcel injections, the redox potential is <0, which is even more favorable to MNA.

The studies determined that MNA is viable and appropriate for TCE, and would be protective of the sentinel well (SC-35D).

3.8 Projected Time to Achieve TCE Regulatory Standards

The time to achieve cleanup goals is a fundamental factor in evaluating a remedial approach. It is appropriate to compare the time to cleanup for ISR (the focus of the Pilot Program) versus pump and treat (the technology specified in the ROD).

TRC performed modeling to predict the time to achieve regulatory standards (1 ug/L) for TCE[1]. The EPA's BIOSCREEN modeling program and the EPA's Batch Flushing Model were used to predict the remedial timeframe (RTF) for ISR followed by MNA and the EPA's Batch Flushing Model was used to predict the RTF for pump & treat. The modeling results, included in Appendix C, indicate that the pump and treat technology would achieve regulatory standards for chromium in approximately 80 to 100 years. Comparatively, the modeling results indicate that ISR, as implemented in 2011 and followed by MNA, would achieve regulatory standards in approximately 30 to 40 years[2].

Compared to pump and treat, ISR followed by MNA would achieve cleanup goals for TCE considerably faster than pump and treat.

3.9 ISR Pilot Program Effectiveness, Implementability, and Cost

AOC Task IV paragraph G requires that the ISR Pilot Program be evaluated by the following EPA screening criteria:

- Effectiveness;
- Implementability; and
- Cost.

EPA defines these three criteria as follows.

Effectiveness: The evaluation criterion focuses on the effectiveness of the technology to reduce toxicity, mobility or volume of contamination for long-term protection and in complying with project objectives. The criterion also evaluates potential impacts to human health and the environment during construction and implementation, as well as how proven and reliable the process is with regards to site-specific conditions.

[1] For the upper zone, modeling simulates TCE fate & transport from an on-site source area near well MW-20S; for the lower zone, modeling simulates TCE fate & transport at the Farm Parcel from off-site sources.
[2] These estimates assume that there are no new TCE releases or contributions from off-site sources.

Implementability: This criterion takes in both the technical and administrative feasibility of the technology, and includes evaluation of pretreatment requirements, residual management, and the relative ease or difficulty in performing the operation and maintenance (O&M) requirements. Technologies that are ineffective or unworkable at the Site are eliminated by this criterion.

Relative Cost: The cost analysis is based on engineering judgment; the technology being evaluated as to whether costs are low, moderate or high relative to other options of similar technology type. For purposes of establishing a comparison to ISR, TRC used pump and treat, the technology cited in the ROD.

The AOC further suggests that the evaluation include a comparison of observed results to predicted results.

Each of these factors is discussed in the subsections below.

3.9.1 Effectiveness

The ISR Pilot Program has reduced the toxicity (by converting hexavalent chromium to the less toxic trivalent form), mobility (by precipitating chromium out of solution) AND volume (the overall plume volume, as defined by the plume limits at 70 µg/L is less than $1/10^{th}$ its pre-existing size). Further, studies show that the improvements are stable and irreversible, so the ISR Pilot Program provides a long-term, reliable protection. The environment, workers, and the public were protected during field operations and work was completed with no reported concerns.

The time to achieve cleanup goals is a fundamental factor in effectiveness. As discussed above, the projected time to achieve regulatory standards for chromium for ISR (followed by MNA) is approximately 120 to 330, and for pump and treat is approximately 440 to 600 years. The time to cleanup for ISR for Chromium can be revisited (possibly improved) after the 2014 injections are completed. Similarly, the predicted time to achieve regulatory standards for TCE for ISR is approximately 30 to 40 years, and for pump and treat is approximately 80 to 100 years. Compared to pump and treat, the ISR would achieve cleanup goals much faster than pump and treat, and, therefore, ISR is effective and more efficient.

EPA also considers sustainability as part of remedy effectiveness. Sustainable, or “green” practices, are preferred over less-sustainable practices. For groundwater remediation, EPA cites four basic green parameters, namely, water conservation, energy conservation, efficiency, and lifecycles.

<u>Water Conservation</u>
The pump and treat system removed approximately 750,000,000 gallons of valuable groundwater over its operation. The ISR program used only approximately 10,000,000 gallons of water (and recycled it into the aquifer). Clearly ISR is dramatically more sustainable/green relative to water conservation than pump and treat.

Energy Conservation
The pump and treat used the energy equivalent to 30 homes, 24 hours a day for decades. ISR used solar panels and hydro-powered equipment, with supplemental use of temporary generators (9 months). Clearly, ISR is dramatically more sustainable/green relative to energy conservation that the pump and treat technology.

Efficiency
Pump and treat had heavy water use, and heavy energy use, and achieved plume size reduction of only 2 times in 20 years. ISR had low water use, low energy use, and achieved 60 times plume reduction in 9 months of injections. Clearly, ISR is dramatically more sustainable/green relative to efficiency.

Lifecycle
As discussed above, the time to achieve cleanup goals is much short for ISR than it is for pump and treat. Accordingly, ISR is more sustainable/green than pump and treat relative to lifecycle considerations.

ISR is far more sustainable than pump and treat.

The ISR Pilot Program is far more effective than pump and treat.

3.9.2 Implementability

The ISR Pilot Program was performed using commercially available materials and readily available labor. Monitoring, which is an integral portion of both the active/injection phase, as well as the MNA/O&M phase is readily accomplished. The administrative requirements of the ISR Pilot Program centered on EPA approval of the work, and NJDEP issuance of Permit By Rule Equivalences, which the agencies provided in a thorough and timely manner. A small number of injection wells required a wetlands-buffer permit, which was readily obtained from the NJDEP. Accordingly, the ISR Pilot Program was readily implemented from an administrative perspective.

One of the advantages of in situ processes is that no residual waste is generated (compared to pump and treat, which requires constant discharge of residual water, and landfill disposal of treatment solids).

The ISR Pilot Program was readily implementable.

3.9.3 Cost

TRC has spent $6,600,000 on the ISR Pilot Program. These investments have reduced shallow TCE concentration by 100% at the source key well (SC-20S), and chromium concentrations within the bulk of the plume by >95% in less than 9 months of injection work. Comparatively, the pump and treat system construction and operation cost approximately $30,000,000, reduced chromium plume volume by less than 50% over 20 years. While the ISR cost has been quite significant, the RELATIVE cost (return on investment and cost/benefit analysis) of ISR is more effective than pump and treat.

3.9.4 Results Versus Expectations

The ISR Pilot Program has exceeded all expectations. The percentage-removal for both chromium and TCE significantly exceed predicted results.

The degree of stability and irreversibility are consistent with expectations.

4.0 OVERALL ISR PILOT PROGRAM CONCLUSIONS

It is concluded that the ISR injection system, injection well network, and well design were effective for the distribution of CPS. The effectiveness of CPS and EVO treatment is demonstrated by:

- Rapid and sustained favorable geochemical shifts;
- Rapid, complete, stable and permanent reduction of dissolved chromium towards target concentrations;
- Chromium and TCE ISR is in the more active stages and will remain so for some time;
- Enhanced natural attenuation capacity due to mobilizing native iron; and
- Reduced remediation timeframes.

The ISR Pilot Program is effective, implementable, and has favorable relative costs. The ISR Pilot Program results have exceeded expectations.

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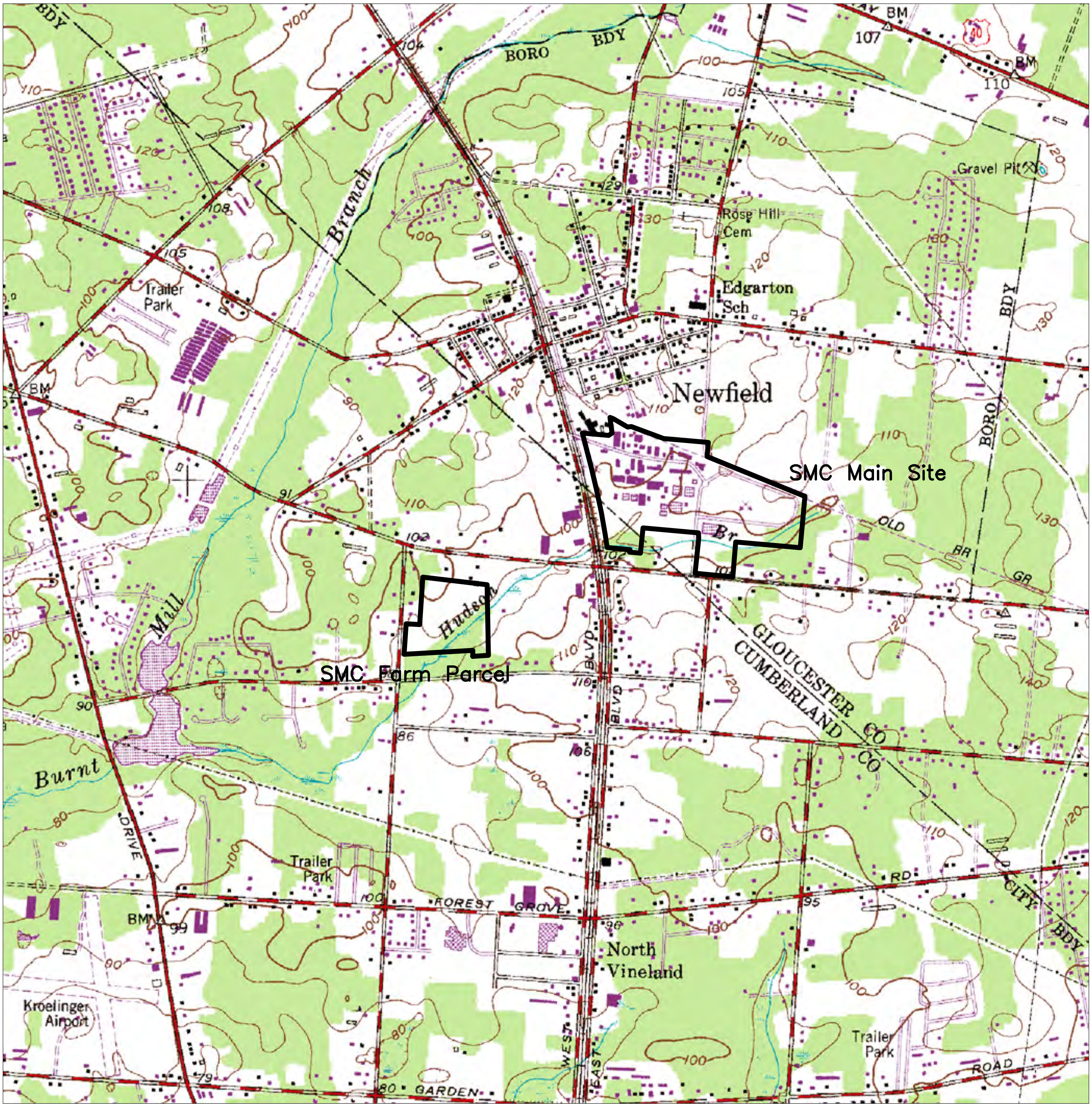
Figures



SOURCE: NEWFIELD, N.J. QUADRANGLE, 1953, PHOTOREVISED 1994,
7.5 MINUTE SERIES (USGS TOPOGRAPHIC MAP)

SITE PROPERTY BOUNDARY

N

0 2000 FT.

APPROXIMATE SCALE

QUADRANGLE LOCATION

TRC ENVIRONMENTAL CORP.
57 East Willow Street
Millburn, New Jersey 07041

SITE LOCATION MAP

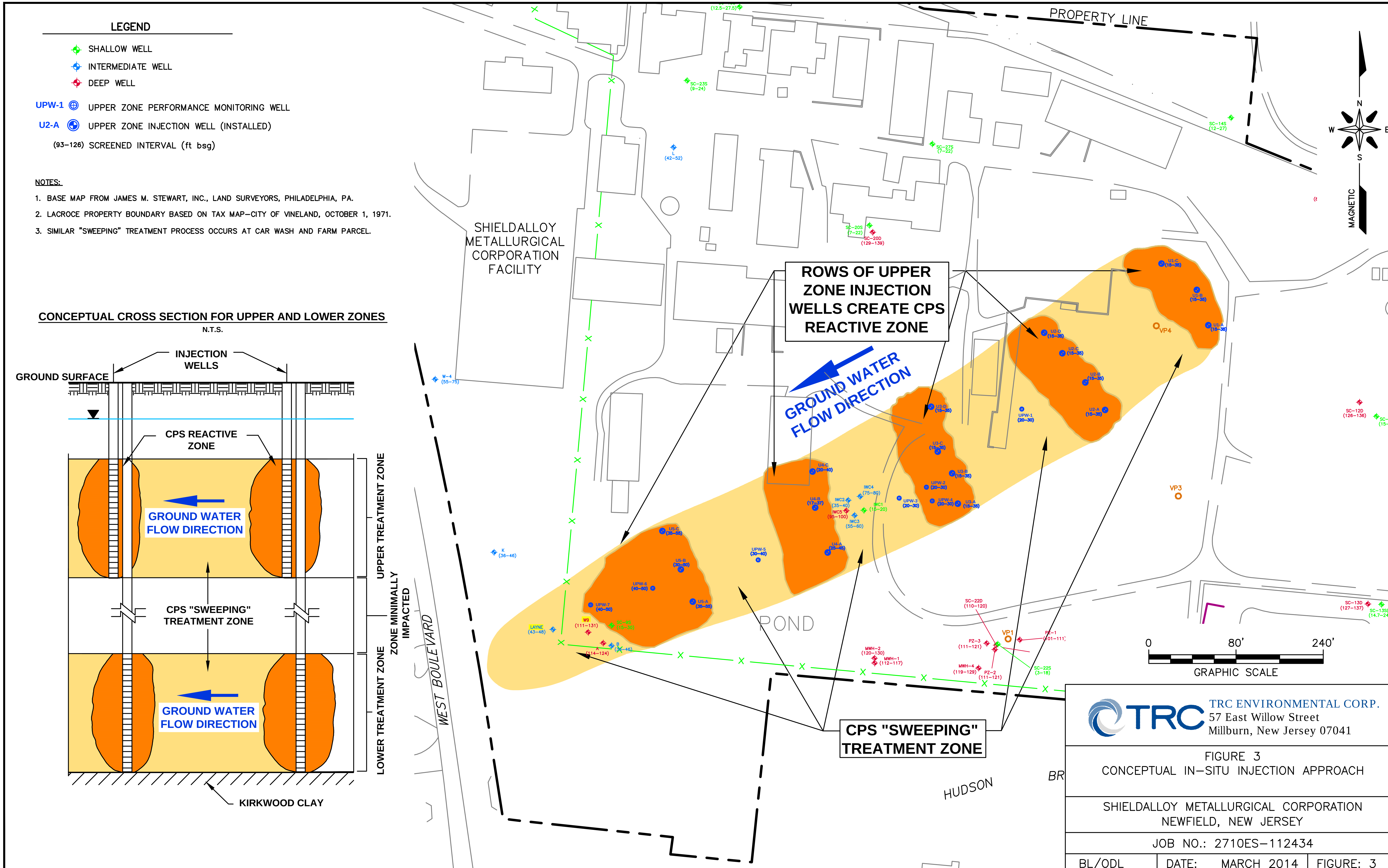
SHIELDALLOY METALLURGICAL CORPORATION
NEWFIELD, NEW JERSEY

JOB NO.: 2710ES-112434

BR/TH	DATE: FEBRUARY 2013	FIGURE: 1

\\MILLBURN-FP2\DRAFTINGFILES\CAD FILES\WORK\2710ES\2014_03 ISR EVALUATION REPORT\FIGURE 1 SITE LOCATION MAP.DWG 03/31/2014 02:53:20PM TAB: LAYOUT

FILE: \\MILLBURN-FP2\DRAFTINGFILES\CAD FILES\WORK\2710ES\2014_03 ISR EVALUATION REPORT\FIGURE 2 SITE PLAN.DWG, DATE: 03/31/2014 02:57:04PM



FILE: C:\USERS\CGEORGIADIS\APPDATA\LOCAL\TEMP\ACPUBLISH_6384\FIGURE 3 CONCEPTUAL IN-SITU INJECTION APPROACH.DWG, DATE: 03/31/2014 03:01:49PM

Appendix A

APPENDIX A - CPS FATE & TRANSPORT – CPS RESIDENCE TIME

TRC utilized AFCEE BIOSCREEN (USEPA, 1996), an EPA-supported analytical solute transport model to predict the fate and transport of CPS. Specifically, the model was used to estimate the residence time, during which sulfide, the active component of CPS, remains active (*i.e.*, effective for the reduction/precipitation of chromium). Although it was developed to evaluate the natural attenuation of petroleum hydrocarbons, BIOSCREEN can be used as a general fate & transport model, because the key transport processes considered in BIOSCREEN, specifically, advection, adsorption, dispersion, decay and source term, are applicable to all chemicals. However, special treatment is necessary to handle the adsorption and decay terms because they are chemical-independent. A more detailed description of the use of BIOSCREEN for the evaluation of CPS fate & transport was presented in Appendix N of the ISR Pilot Test Report & Expanded ISR Pilot Program Workplan prepared and submitted by TRC in February 2011 (TRC, 2011).

TRC used site-specific input parameters for the aquifer characteristics and CPS/sulfide mass and concentrations for the various areas of the Site (*i.e.,* facility *vs.* farm parcel) and zones of the aquifer (lower zone *vs.* upper zone), based on extensive laboratory and field testing and monitoring. Simulations were run for both the upper zone, and lower zone, because each zone has different hydrogeologic properties. Also, TRC modeled both the Facility scenario and the Farm Parcel scenario, to reflect the differing site conditions, and provide a reasonable range of estimates. A summary of CPS related input parameters is presented below:

- The model simulates sulfide transport from an equivalent source (CPS injection row).
- The CPS (sulfide) mass at the equivalent source is the sum of CPS (sulfide) mass injected at the respective row throughout the ISR pilot program during 2011 through 2013 (one run accounted for the planned supplemental injection in the lower zone at the Farm Parcel).
- The sulfide concentration at the source was calculated based on a dilution ratio of 50 (as applied in the field) and a sulfide content of 7% in 29% CPS solution (manufacturer).
- The source thickness is equivalent to the CPS injection interval (20 and 30 feet).
- A vertical dispersion factor of 10 was considered for the lower zone to account for density transport of large mass of concentrated CPS.
- Sorption of CPS is neglected.
- A CPS half-life of 0.055 year was used based on the CPS column study (TRC, 2011).
- The target sulfide concentration, at which CPS will have limited effects on the remediation of the dissolved chromium plume, is assumed to be 1 mg/l for the upper zone and 10 mg/l for the lower zone. The higher value for the lower zone is to account for the higher CPS depletion rate due to the lower pH and higher iron content. This concentration, which is based on the CPS column studies (sulfide was active at 0.1-1 mg/l) is not a "bright line", but, rather a reasonable point with which to estimate the effective active remediation time.

Modeling predicted the CPS (sulfide) active residence time is 5-10 years in the upper aquifer zone, and 20-35 years in the lower aquifer zone. The time in the lower zone is longer, due to the larger injected CPS mass/loading and lower hydraulic conductivities in the lower zone. Monitoring can be performed to better assess the CPS residence time at the site.

The model input and output are presented below.

LOWER ZONE AT FACILITY (2011 & 2012 INJECTIONS)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

SMC - Facility
CPS F&T - Lower Zone
Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
or 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).
0.02

Variable* → Data used directly in model.
20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	131.7	(ft/yr)
or		or	
Hydraulic Conductivity	K	1.1E-02	(cm/sec)
Hydraulic Gradient	i	0.003	(ft/ft)
Porosity	n	0.25	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	32.3	(ft)
Transverse Dispersivity*	alpha y	3.2	(ft)
Vertical Dispersivity*	alpha z	32.3	(ft)
or		or	
Estimated Plume Length	Lp	2000	(ft)

3. ADSORPTION

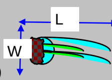
Retardation Factor*	R	1.00	(-)
or		or	
Soil Bulk Density	rho	1.7	(kg/l)
Partition Coefficient	Koc	0	(L/kg)
FractionOrganicCarbon	foc	0.0E+0	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	1.3E+1	(per yr)
or		or	
Solute Half-Life	t-half	0.055	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO		(mg/L)
Delta Nitrate*	NO3		(mg/L)
Observed Ferrous Iron*	Fe2+		(mg/L)
Delta Sulfate*	SO4		(mg/L)
Observed Methane*	CH4		(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	35	(yr)



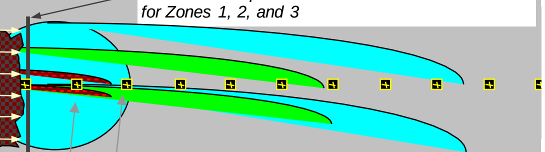
6. SOURCE DATA

Source Thickness in Sat.Zone* 25 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*	Zone
60	1,460	1
40	1,460	2
40	1,460	3
40	1,460	4
60	1,460	5

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Source Halflife (see Help): 5 | 5 (yr)

Inst. React. | 1st Order

Soluble Mass 62,001 (Kg)

In Source CPS Mass

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | RUN ARRAY | Help | Recalculate
View Output | View Output | Paste Example Dataset
Restore Formulas for Vs,

Sulfide Mass @2011-12 =	*765,594*	*lbs @*	*28 wells at*	*5*	*wells per line*	*62,001*	*kg/PBR line*	
Sulfide concentration @ PBR =	*1,460*	*mg/l =*	*0.146%*		*# of lines =*	*5.6*		

Hydraulic Conductivity =	30	ft/day	Vertical Dispersion Factor - Density equivalence=	10		# Wells =	28	
Dilution Ratio =	50		CPS mass -2011 =	1,856,200	lbs	Well spacing =	70	ft
Initial sulfide concentration	7%		CPS mass -2012 =	1,185,200	lbs	Line/Row length =	280	ft
Sulfide in 29% CPS=	25%		CPS Mass @ 2011-12=	3,041,400	lbs	Plume width =	400	ft

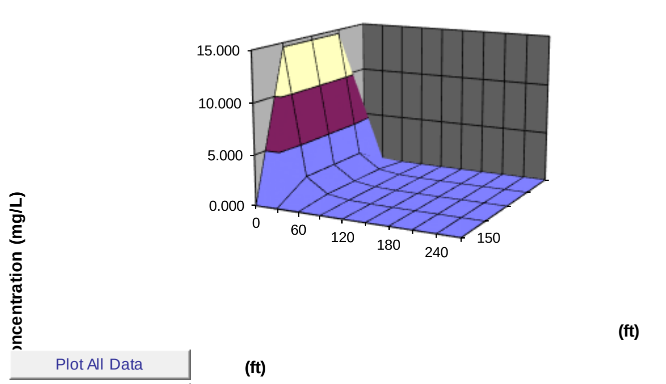
DISSOLVED SULFIDE CONCENTRATIONS IN PLUME (mg/L at Z=0) - LOWER ZONE @ SMC FACILITY

Model to Display: No Degradation | 1st Order Decay | Instantaneous

Transverse Distance (ft) ↓ \ Distance from Source (ft)	0	30	60	90	120	150	180	210	240	270	300
150	0.000	0.029	0.026	0.011	0.004	0.001	0.000	0.000	0.000	0.000	0.000
75	14.584	1.881	0.405	0.098	0.025	0.007	0.002	0.000	0.000	0.000	0.000
0	14.584	1.882	0.410	0.101	0.026	0.007	0.002	0.001	0.000	0.000	0.000
-75	14.584	1.881	0.405	0.098	0.025	0.007	0.002	0.000	0.000	0.000	0.000
-150	0.000	0.029	0.026	0.011	0.004	0.001	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	-	-	-	-	-	-	-	-	-	-	-

Can't calculate mass flux when vertical dispersivity not equal to 0

Time: **35 Years** Target Level: **10** mg/L Displayed Model: **1st Order Decay**



Plot All Data
Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

See Gallons

Plume Mass if No Biodegradation	Can't Calc.	(Kg)
- Actual Plume Mass	Can't Calc.	(Kg)
= Plume Mass Removed by Biodeg	-	(Kg)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	Nitrate	Iron II	Sulfate	Methane	
na	na	na	na	na	(Kg)

Contam. Mass in Source (t=0 Years)	62001.4	(Kg)
Contam. Mass in Source Now (t=35Years)	619.4	(Kg)
Current Volume of Groundwater in Plume	Can't Calc.	(ac-ft)
Flowrate of Water Through Source Zone	Can't Calc.	(ac-ft/yr)

Mass HELP | Return to Input | Recalculate

UPPER ZONE AT FACILITY (2011 & 2012 INJECTIONS)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

SMC - FACILITY
CPS F&T - UPPER
Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
or 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).
0.02

Variable* → Data used directly in model.
20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	307.2	(ft/yr)
or		or	
Hydraulic Conductivity	K	2.5E-02	(cm/sec)
Hydraulic Gradient	i	0.003	(ft/ft)
Porosity	n	0.25	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	17.9	(ft)
Transverse Dispersivity*	alpha y	1.8	(ft)
Vertical Dispersivity*	alpha z	1.8	(ft)
or		or	
Estimated Plume Length	Lp	500	(ft)

3. ADSORPTION

Retardation Factor*	R	1.00	(-)
or		or	
Soil Bulk Density	rho	1.7	(kg/l)
Partition Coefficient	Koc	0	(L/kg)
FractionOrganicCarbon	foc	0.0E+0	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	1.3E+1	(per yr)
or		or	
Solute Half-Life	t-half	0.055	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO		(mg/L)
Delta Nitrate*	NO3		(mg/L)
Observed Ferrous Iron*	Fe2+		(mg/L)
Delta Sulfate*	SO4		(mg/L)
Observed Methane*	CH4		(mg/L)

5. GENERAL

Modeled Area Length*	200	(ft)
Modeled Area Width*	200	(ft)
Simulation Time*	5.00	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 20 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

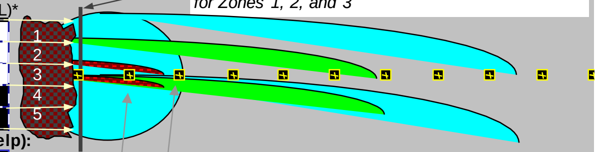
Source Zones:

Width* (ft)	Conc. (mg/L)*	Zone
50	1,460	1
25	1,460	2
25	1,460	3
25	1,460	4
50	1,460	5

Source Halflife (see Help):

Inst. React.	1st Order	
<1	<1	(yr)

Soluble Mass 7,870 (Kg)
In Source CPS Mass



7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	20	40	60	80	100	120	140	160	180	200

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — View Output
RUN ARRAY — View Output
Help — Recalculate
Paste Example Dataset
Restore Formulas for Vs,

Sulfide mass -2012-13 =	*73,755*	*lbs @*	*17 wells at*	*4*	*wells in line*	*7,870*	kg/line @ well spacing =	70	ft	
Sulfide concentration in CPS=	*1,460*	*mg/l =*	*0.1460%*		*# of lines =*	*4.25*				
Initial sulfide concentration	7%	Dilution Ratio =	50		line =	150 ft	plume width =	220 ft		
% Sulfide in CPS=	25%									
Hydraulic Conductivity =	70 ft/day		Vertical Dispersion Factor - Density equivalence=				1			
CPS Mass @ 2011=	148,000	lbs								
CPS Mass @ 2012 =	145,000	lbs	CPS mass -2011-12 =	293,000	lbs					

DISSOLVED CPS CONCENTRATIONS IN PLUME (mg/L at Z=0) - UPPER ZONE @ SMC FACILITY (2011-2012)

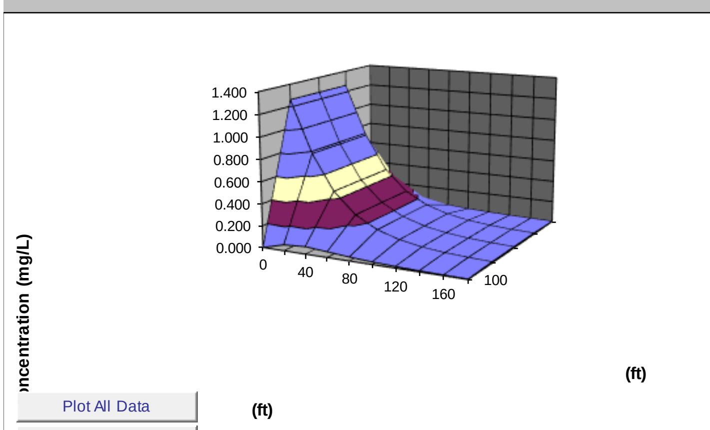
Transverse Distance (ft) ↓ — ***Distance from Source (ft)***

	0	20	40	60	80	100	120	140	160	180	200
100	0.000	0.055	0.068	0.052	0.035	0.023	0.015	0.009	0.006	0.004	0.002
50	1.259	0.782	0.456	0.262	0.152	0.088	0.052	0.031	0.018	0.011	0.006
0	1.259	0.782	0.456	0.264	0.154	0.091	0.054	0.032	0.019	0.012	0.007
-50	1.259	0.782	0.456	0.262	0.152	0.088	0.052	0.031	0.018	0.011	0.006
-100	0.000	0.055	0.068	0.052	0.035	0.023	0.015	0.009	0.006	0.004	0.002
MASS FLUX (mg/day)	-	-	-	-	-	-	-	-	-	-	-

Can't calculate mass flux when vertical dispersivity not equal to 0

Time: **5 Years** Target Level: **1.0** mg/L Displayed Model: **1st Order Decay**

Model to Display: No Degradation / 1st Order Decay / Instantaneous



Plot All Data
Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

See Gallons

Plume Mass if No Biodegradation	Can't Calc.	(Kg)
- Actual Plume Mass	Can't Calc.	(Kg)
= Plume Mass Removed by Biodeg	-	(Kg)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	(Kg)

Contam. Mass in Source (t=0 Years)	7870.4	(Kg)
Contam. Mass in Source Now (t=5Years)	6.8	(Kg)
Current Volume of Groundwater in Plume	Can't Calc.	(ac-ft)
Flowrate of Water Through Source Zone	Can't Calc.	(ac-ft/yr)

Mass HELP — Return to Input — Recalculate

LOWER ZONE AT FARM PARCEL (2012 & 2013 INJECTIONS)

BIOSCREEN Natural Attenuation Decision Support System
Air Force Center for Environmental Excellence — *Version 1.4*

SMC - Farm Parcel
CPS F&T - lower
Run Name

Data Input Instructions:
115 → 1. Enter value directly....or
or 0.02 → 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).
Variable* → Data used directly in model.
20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	131.7	(ft/yr)
or		or	
Hydraulic Conductivity	K	1.1E-02	(cm/sec)
Hydraulic Gradient	i	0.003	(ft/ft)
Porosity	n	0.25	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	17.9	(ft)
Transverse Dispersivity*	alpha y	1.8	(ft)
Vertical Dispersivity*	alpha z	17.9	(ft)
or		or	
Estimated Plume Length	Lp	500	(ft)

3. ADSORPTION

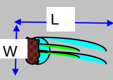
Retardation Factor*	R	1.00	(-)
or		or	
Soil Bulk Density	rho	1.7	(kg/l)
Partition Coefficient	Koc	0	(L/kg)
FractionOrganicCarbon	foc	0.0E+0	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	1.3E+1	(per yr)
or		or	
Solute Half-Life	t-half	0.055	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO		(mg/L)
Delta Nitrate*	NO3		(mg/L)
Observed Ferrous Iron*	Fe2+		(mg/L)
Delta Sulfate*	SO4		(mg/L)
Observed Methane*	CH4		(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	200	(ft)
Simulation Time*	20	(yr)



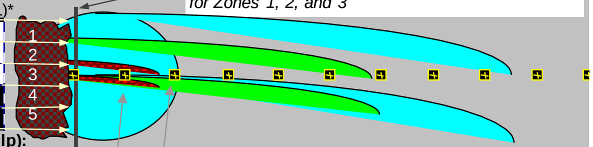
6. SOURCE DATA

Source Thickness in Sat.Zone* 30 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*	Zone
60	1,460	1
40	1,460	2
40	1,460	3
40	1,460	4
60	1,460	5

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Source Halflife (see Help):
3 | 3 (yr)
Inst. React. | 1st Order
Soluble Mass 45,607 (Kg)
In Source CPS Mass

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | RUN ARRAY | Help | Recalculate
View Output | View Output | Paste Example Dataset
Restore Formulas for Vs,

Sulfide mass -2012-13 =	362,029	lbs @	18 wells at	5	wells in line	45,607	kg/line @ well spacing = 70 ft
Sulfide concentration in CPS=	1,460	mg/l =	0.146%		# of lines =	3.6	
Initial sulfide concentration	7%	Dilution Ratio =	50		line = 280 ft	plume width =	400 ft
% Sulfide in CPS=	25%						
Hydraulic Conductivity =	30 ft/day		Vertical Dispersion Factor - Density equivalence=			10	
CPS Mass @ 2012=	1,027,875	lbs	CPS mass @2012 & 13 =	1,438,199	lbs		
CPS Mass @ 2013 =	410,324	lbs					

DISSOLVED CPS CONCENTRATIONS IN PLUME (mg/L at Z=0) - LOWER ZONE @ SMC FARM PARCEL

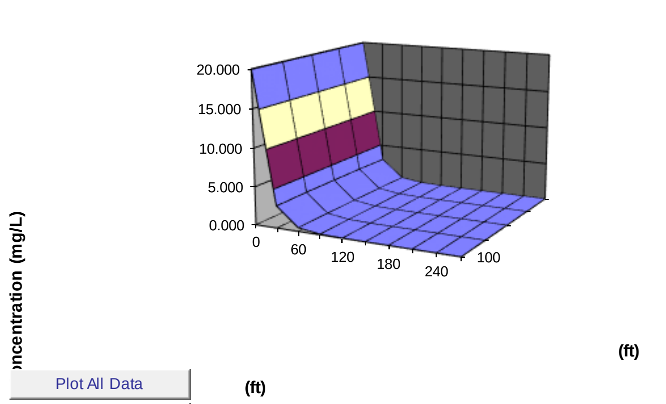
Transverse Distance (ft) — ***Distance from Source (ft)***

Transverse Distance (ft)	0	30	60	90	120	150	180	210	240	270	300
100	19.930	2.879	0.473	0.087	0.017	0.003	0.001	0.000	0.000	0.000	0.000
50	19.930	2.959	0.518	0.100	0.020	0.004	0.001	0.000	0.000	0.000	0.000
0	19.930	2.959	0.518	0.100	0.020	0.004	0.001	0.000	0.000	0.000	0.000
-50	19.930	2.959	0.518	0.100	0.020	0.004	0.001	0.000	0.000	0.000	0.000
-100	19.930	2.879	0.473	0.087	0.017	0.003	0.001	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	-	-	-	-	-	-	-	-	-	-	-

Can't calculate mass flux when vertical dispersivity not equal to 0

Time: **20 Years** — Target Level: 10 mg/L — Displayed Model: **1st Order Decay**

Model to Display: No Degradation | 1st Order Decay | Instantaneous



Plot All Data
Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

See Gallons

Plume Mass if No Biodegradation	Can't Calc.	(Kg)
- Actual Plume Mass	Can't Calc.	(Kg)
= Plume Mass Removed by Biodeg	-	(Kg)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	Nitrate	Iron II	Sulfate	Methane	
na	na	na	na	na	(Kg)

Contam. Mass in Source (t=0 Years)	45607.1	(Kg)
Contam. Mass in Source Now (t=20Years)	622.6	(Kg)
Current Volume of Groundwater in Plume	Can't Calc.	(ac-ft)
Flowrate of Water Through Source Zone	Can't Calc.	(ac-ft/yr)

Mass HELP | Return to Input | Recalculate

LOWER ZONE AT FARM PARCEL (2012, 2013 & PLANNED 2014 INJECTIONS)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

SMC - Farm Parcel
CPS F&T - lower
Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
or
0.02 → 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* → Data used directly in model.
20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	131.7	(ft/yr)
or		or	
Hydraulic Conductivity	K	1.1E-02	(cm/sec)
Hydraulic Gradient	i	0.003	(ft/ft)
Porosity	n	0.25	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	17.9	(ft)
Transverse Dispersivity*	alpha y	1.8	(ft)
Vertical Dispersivity*	alpha z	17.9	(ft)
or		or	
Estimated Plume Length	Lp	500	(ft)

3. ADSORPTION

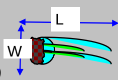
Retardation Factor*	R	1.00	(-)
or		or	
Soil Bulk Density	rho	1.7	(kg/l)
Partition Coefficient	Koc	0	(L/kg)
FractionOrganicCarbon	foc	0.0E+0	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	1.3E+1	(per yr)
or		or	
Solute Half-Life	t-half	0.055	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO		(mg/L)
Delta Nitrate*	NO3		(mg/L)
Observed Ferrous Iron*	Fe2+		(mg/L)
Delta Sulfate*	SO4		(mg/L)
Observed Methane*	CH4		(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	25.00	(yr)



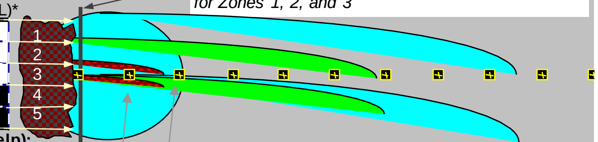
6. SOURCE DATA

Source Thickness in Sat.Zone* 30 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*	Zone
60	1,460	1
40	1,460	2
40	1,460	3
40	1,460	4
60	1,460	5

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Source Halflife (see Help):

Inst. React.	1st Order	
4	4	(yr)

Soluble Mass 52,128 (Kg)
In Source CPS Mass

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | RUN ARRAY | Help | Recalculate
View Output | View Output | Paste Example Dataset
Restore Formulas for Vs,

Sulfide mass -2012-13 = 413,794 *lbs @* 18 *wells at* 5 *wells in line* 52,128 kg/line @ well spacing = 70 ft
Sulfide concentration in CPS= 1,460 *mg/l =* 0.146% *# of lines =* 3.6
Initial sulfide concentration 7% Dilution Ratio = 50 line = 280 ft plume width = 400 ft
% Sulfide in CPS= 25%
Hydraulic Conductivity = 30 ft/day Vertical Dispersion Factor - Density equivalence= 10
CPS Mass @ 2012= 1,027,875 lbs CPS mass -2012-2014 = 1,643,839 lbs
CPS Mass @ 2013 = 410,324 lbs Est. CPS mass @2014 = 205,640 lbs

DISSOLVED CPS CONCENTRATIONS IN LOWER ZONE (mg/L at Z=0) @ SMC FARM PARCEL (2012-2014 INJECTIONS)

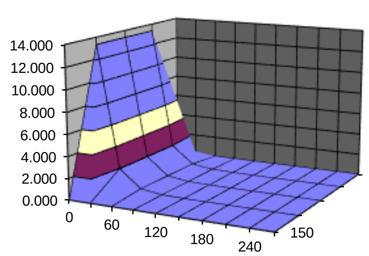
Transverse Distance (ft) — *Distance from Source (ft)* — *Model to Display:*

	0	30	60	90	120	150	180	210	240	270	300
150	0.000	0.004	0.007	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000
75	13.332	1.967	0.342	0.065	0.013	0.003	0.001	0.000	0.000	0.000	0.000
0	13.332	1.967	0.342	0.066	0.013	0.003	0.001	0.000	0.000	0.000	0.000
-75	13.332	1.967	0.342	0.065	0.013	0.003	0.001	0.000	0.000	0.000	0.000
-150	0.000	0.004	0.007	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	-	-	-	-	-	-	-	-	-	-	-

Can't calculate mass flux when vertical dispersivity not equal to 0

Time: **25 Years** Target Level: 10 mg/L Displayed Model: **1st Order Decay**

No Degradation | *1st Order Decay* | *Instantaneous*



oncentration (mg/L)
(ft)
(ft)

Plot All Data
Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

See Gallons

Plume Mass if No Biodegradation	Can't Calc.	(Kg)
- Actual Plume Mass	Can't Calc.	(Kg)
= Plume Mass Removed by Biodeg	-	(Kg)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	Nitrate	Iron II	Sulfate	Methane	
na	na	na	na	na	(Kg)

Contam. Mass in Source (t=0 Years)	52128.2	(Kg)
Contam. Mass in Source Now (t=25Years)	476.0	(Kg)
Current Volume of Groundwater in Plume	Can't Calc.	(ac-ft)
Flowrate of Water Through Source Zone	Can't Calc.	(ac-ft/yr)

Mass HELP | Return to Input | Recalculate

UPPER ZONE AT FARM PARCEL (2012 & 2013 INJECTIONS)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

SMC Farm Parcel
CPS F&T - UPPER
Run Name

Data Input Instructions:
115 → 1. Enter value directly....or
or
0.02 → 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).
Variable* → Data used directly in model.
20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	219.4	(ft/yr)
or		or	
Hydraulic Conductivity	K	1.8E-02	(cm/sec)
Hydraulic Gradient	i	0.003	(ft/ft)
Porosity	n	0.25	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	17.9	(ft)
Transverse Dispersivity*	alpha y	1.8	(ft)
Vertical Dispersivity*	alpha z	1.8	(ft)
or		or	
Estimated Plume Length	Lp	500	(ft)

3. ADSORPTION

Retardation Factor*	R	1.00	(-)
or		or	
Soil Bulk Density	rho	1.7	(kg/l)
Partition Coefficient	Koc	0	(L/kg)
FractionOrganicCarbon	foc	0.0E+0	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	1.3E+1	(per yr)
or		or	
Solute Half-Life	t-half	0.055	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO		(mg/L)
Delta Nitrate*	NO3		(mg/L)
Observed Ferrous Iron*	Fe2+		(mg/L)
Delta Sulfate*	SO4		(mg/L)
Observed Methane*	CH4		(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	200	(ft)
Simulation Time*	5.00	(yr)

L
W

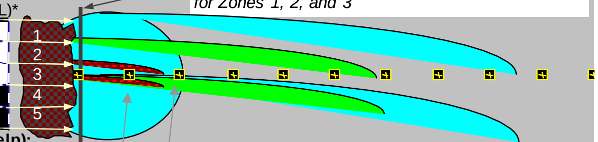
6. SOURCE DATA

Source Thickness in Sat.Zone* 20 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*	Zone
50	1,460	1
25	1,460	2
25	1,460	3
25	1,460	4
50	1,460	5

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Source Halflife (see Help):

<1	<1	(yr)
Inst. React.	1st Order	
Soluble Mass	9,643	(Kg)
In Source CPS Mass		

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | RUN ARRAY | Help | Recalculate
View Output | View Output | Paste Example Dataset
Restore Formulas for Vs,

Sulfide mass -2012-13 = 90,369 *lbs @* 17 *wells at* 4 *wells in line* 9,643 kg/line @ well spacing = 70 ft
Sulfide concentration in CPS= 1,460 *mg/l =* 0.1460% *# of lines =* 4.25
Initial sulfide concentration 7% Dilution Ratio = 50 line = 150 ft plume width = 220 ft
% Sulfide in CPS= 25%
Hydraulic Conductivity = 50 ft/day Vertical Dispersion Factor - Density equivalence= 1
CPS mass -2012-13 = 359,000 lbs

Transverse **DISSOLVED CPS CONCENTRATIONS IN PLUME (mg/L at Z=0) - UPPER ZONE @ SMC FARM PARCEL (2012-2013)**

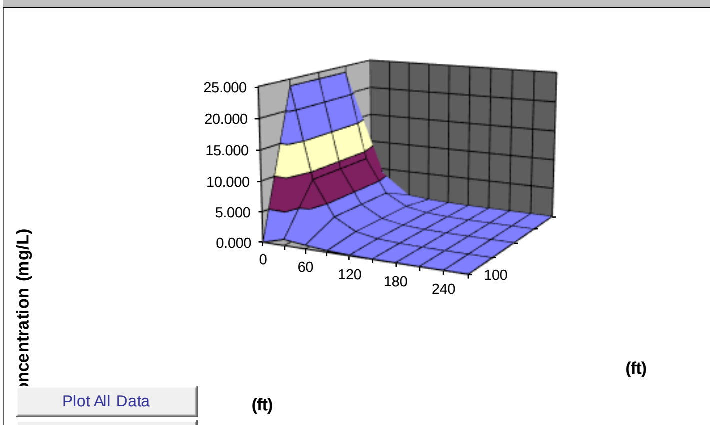
Transverse Distance (ft)	0	30	60	90	120	150	180	210	240	270	300
100	0.000	1.003	0.590	0.251	0.100	0.038	0.015	0.006	0.002	0.001	0.000
50	23.876	8.791	2.976	1.015	0.351	0.123	0.044	0.016	0.006	0.002	0.001
0	23.876	8.792	2.992	1.034	0.364	0.130	0.047	0.017	0.006	0.002	0.001
-50	23.876	8.791	2.976	1.015	0.351	0.123	0.044	0.016	0.006	0.002	0.001
-100	0.000	1.003	0.590	0.251	0.100	0.038	0.015	0.006	0.002	0.001	0.000
MASS FLUX (mg/day)	-	-	-	-	-	-	-	-	-	-	-

Distance from Source (ft)

Can't calculate mass flux when vertical dispersivity not equal to 0

Time: **5 Years** Target Level: **1.0** mg/L Displayed Model: **1st Order Decay**

Model to Display: No Degradation | 1st Order Decay | Instantaneous



Plot All Data
Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

See Gallons

Plume Mass if No Biodegradation	Can't Calc.	(Kg)
- Actual Plume Mass	Can't Calc.	(Kg)
= Plume Mass Removed by Biodeg	-	(Kg)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	Nitrate	Iron II	Sulfate	Methane	
na	na	na	na	na	(Kg)

Contam. Mass in Source (t=0 Years)	9643.2	(Kg)
Contam. Mass in Source Now (t=5Years)	157.7	(Kg)
Current Volume of Groundwater in Plume	Can't Calc.	(ac-ft)
Flowrate of Water Through Source Zone	Can't Calc.	(ac-ft/yr)

Mass HELP | Return to Input | Recalculate

Appendix B

Estimate of Time to Reduce Chromium
to 70 ug/L in Groundwater through
Groundwater Extraction
vs.
CPS Injection and MNA
Shieldalloy Site
Newfield, NJ

Calculation By: JSH
Checked By: NMR

Problem Statement : *Estimate the time required to reduce the concentration of total chromium dissolved in groundwater to the 70 µg/l NJDEP Groundwater Quality Standard (GWQS) using the existing groundwater extraction system as compared to the time required to achieve the NJDEP GWQS via natural attenuation (MNA) following In Situ Chemical Reduction (ISR) via Calcium Polysulfide (CPS) Injections.*

Cleanup Timeframe for Pump & Treat

The groundwater extraction system, which is currently inactive, is comprised of five wells (Layne & W-9 at the Facility; RW-6s & RW-6D at the Car Wash; and RIW-2 at the Farm Parcel). Three wells (i.e., the Layne Well, RW-6S, and RIW-2) extract groundwater from the upper zone of the aquifer, which is approximately 60 feet thick on average. The two remaining wells (i.e., W-9 and RW-6D) extract groundwater from the lower zone of the aquifer, which is approximately 55 feet thick on average. The total combined pumping rate of the extraction wells based upon data collected between May 2011 and April 2012 was 326 gallons per minute (gpm).

Approach:

The US Environmental Protection Agency (EPA) Batch Flushing Model (EPA, 1988) developed by Gelhar and Wilson (1974) was used to estimate the time to attain the NJDEP GWQS of 70 µg/l for chromium in the aquifer using the existing groundwater extraction system if it continued operating as the remedy for groundwater and no CPS injections had occurred.

The Batch Flushing Model is based upon the following analytical equations:

$$PV = -R*LN(C_s/C_i) \qquad \text{(Equation 1)}$$

Where: PV = The number of pore volumes of clean groundwater that must pass through a contaminated aquifer in order to reduce the concentration of a contaminant of interest in an aquifer (C_i) to a concentration-based cleanup criterion (C_s); and
R = Retardation Factor for the contaminant of interest (dimensionless).

$$t_{pv} = V_{pv}/Q_{gwes} \qquad \text{(Equation 2)}$$

Where: t_{pv} = time to move one pore volume of clean water through a contaminated aquifer;
V_{pv} = Volume of contaminated groundwater in one pore volume, (Length^3) = Area of plume * b * n;
Q_{gwes} = Rate of groundwater extraction (Volume/time);
b = average thickness of zone containing contaminated groundwater (length); and
n = total porosity of aquifer (dimensionless).

$$t_s = PV * t_{pv} \qquad \text{(Equation 3)}$$

Where: t_s = time to achieve cleanup criterion via groundwater extraction.

Assumptions:

The batch flushing model is subject to the following assumptions:
1. There is no ongoing source of contamination to the aquifer (i.e., all source material has been removed and contaminant are present solely in dissolved phase).
2. The aquifer is homogeneous and isotropic and there are no heterogeneities within the aquifer implying that removal of the contaminant of interest from the pore space is uniform throughout the aquifer and reverse matrix diffusion from lower permeability zones is not significant.
3. During pumping, contaminated groundwater is removed from the entire saturated thickness of the aquifer via fully penetrating wells.
4. Flushing is 100 percent efficient in removing contaminants from the aquifer.
5. Contaminant removal from the aquifer occurs only through groundwater extraction.

Since aquifers are rarely homogenous, contaminant removal by groundwater flushing is not 100 percent efficient. Moreover, some residual contaminant mass usually remains following source removal efforts at most sites and most contaminants are present in a sorbed/residual phase. On this basis and additional considerations, EPA has recognized that the pore volume flushing model frequently underestimates the time required to attain cleanup objectives using pump and treat. Consequently, the following adjustment was incorporated into the analysis to provide reasonable estimates of the time to attain the 70 µg/L cleanup level for chromium using the existing groundwater extraction system. This adjustment is conservative as it accounts only for one deviation.

Estimate of Time to Reduce Chromium to 70 ug/L in Groundwater through Groundwater Extraction vs. CPS Injection and MNA
Shieldalloy Site
Newfield, NJ

Calculation By: JSH
Checked By: NMR

Since the groundwater extraction wells are not fully screened across the entire saturated thickness of the aquifer, flow to the recovery wells is distorted and contaminants are not uniformly flushed over the entire thickness of the aquifer during pumping. To account for this inefficiency, an adjustment factor was applied to the groundwater extraction rate based upon the proportion of the aquifer screened by the recovery wells and considering the maxmum attainable specific capacity for each recovery well. Based upon the average thickness of the aquifer (i.e., 115 feet) and using the relationship between maximum attainable specific capacity and percentage of the aquifer screened by a well presented in Driscoll (1986), a correction factor of **2.4** was applied to the cumulative pumping rate for the recovery wells. Calculations used to derive the 2.4 adjustment factor are summarized below.

Recovery Well	Combined Screen length, L (feet)	Average Aquifer Thickness, b (feet)	Adjustment Factor (1)
Layne Well W-9	25	115	3.3
RW-6S RW-6D	65	115	1.5
RIW-2	25	105	2.3
		Average =	2.4

(1) - Adjustment factor estimated using Figure 9.35 of Driscoll (1986).

Input Sources for Batch Flushing Model

1. The average concentration of dissolved chromium detected in the upper and lower plumes above the 70 µg/l NJDEP groundwater criterion prior to CPS injection during April to July 2011 was used for the initial concentration, C_i. For the analysis, the upper and lower zones were evaluated as a single unit (i.e., the average concentration over the plume and combined pumping rate for recovery wells screened in the lower and upper aquifer were used).

2. The cleanup goal for chromium in groundwater was assumed to be 70 µg/l, the NJDEP criterion for chromium in groundwater.

3. The retardation factor for chromium is based upon co-located soil and groundwater samples from the upper and lower zones of the aquifer presented in the TRC technical memorandum entitled *"Procedural Assessment for MNA for Chromium in Groundwater at SMC Site"* submitted to EPA in February 2013 (TRC, 2013a). The retardation factors in the table below represent the geometric mean of retardation factors for the upper and lower zones presented in the technical memorandum describing the assessment of MNA in groundwater at the SMC Site with the highest retardation values for the upper and lower plumes conservatively excluded since these elevated retardation factors were judged to likely overestimate sorption.

4. The volume of the plume was estimated based upon the average area of the plumes in the Upper and Lower zones above the 70 µg/l NJDEP criterion using pre-CPS injection data collected during April-July 2011, an average combined saturated thickness of the Upper and Lower Zones (115 feet) and a total porosity estimated to be approximately 0.4 for the sandy aquifer soil, which is consistent with porosity of aquifer soils measured during the treatability studies (TRC, 2011) and supported by literature values for similar soil types.

5. The rate of groundwater extraction for recovery wells was calculated from pumping records between April 2011 and May 2012 and was adjusted using the adjustment factor identified above to account for pore flushing inefficiency. The plume is assumed to be captured by the combined pumping of the groundwater extraction system.

6. Time increase and adjustment due to the presence of residual phase at source area is neglected (conservative assumption)

Retardation Factor, R	Average Total Chromium Concentration in Groundwater, Ci	Target Cleanup Criterion, C_s	NPV	Average Area of Plume, L	Thickness of Plume, b	Porosity, n	Volume of Contaminated GW in Pore Volume, Vpv	Groundwater Extraction Rate, Q_{GWES} Unadjusted Rate	Groundwater Extraction Rate, Q_{GWES} Adjusted Rate	Time to Remove One Pore Volume, tpv		Time to Reach NJDEP GWQS via Pump&Treat, t_s	
	(µg/l)	(µg/l)		(feet)	(feet)		(feet^3)	(gpm)	(gpm)	(days)	(years)	(days)	(years)
31	6489	70	140.4	881,624	115	0.4	40,554,704	326	136	1551	4.25	217,758	597
23	6489	70	104.2	881,624	115	0.4	40,554,704	326	136	1551	4.25	161,562	443

Estimate of Time to Reduce Chromium to 70 ug/L in Groundwater through Groundwater Extraction vs. CPS Injection and MNA Shieldalloy Site Newfield, NJ

Remediation Timeframe for ISR (CPS Injection) followed by MNA, t_c

During the period between 2012 and 2014, CPS was injected into the plume to reduce chromimum concentrations in groundwater through ISR. Modeling was performed to assess the impact of CPS injections on the chromium plume and to develop post CPS injection target concentrations for chromium at the Farm Parcel, which would not result in an exceedance of groundwater criteria at the downgradient boundary of the Farm Parcel. Results of the modeling were described in a technical memorandum to EPA entitled *"SMC MNA Modeling"* and dated May 28, 2013 (TRC, 2013b). Calibrated model simulations presented in TRC (2013b) were used as a basis to assess the time to achieve the 70 µg/L NJDEP criterion through a combination of CPS injections and MNA using the following approach.

Approach:

The approach for estimating the time to achieve the 70 µg/L NJDEP criterion involved two steps. The initial step involved BIOSCREEN modeling to simulate the reduction of chromium in the Upper and Lower Zones over the period that CPS remains reactive (CPS residence time or reactivity period), which was estimated from CPS fate & transport modeling to be a minimum of 5 years for the Upper Zone of the aquifer and 25 years for the Lower Zone. Predicted chromium concentrations and mass remaining at the source at the end of the CPS reactivity duration simulations were used as input for additional simulations to evaluate the time required to further reduce groundwater concentrations to the 70 µg/L NJDEP criterion through MNA. Details of the approach are summarized below.

1. Calibrated model simulations for the Upper and Lower Zones of the aquifer provided in Attachment 3 of the May 28, 2013 memorandum (TRC, 2013b) were used to simulate ISR of chromium by CPS. Except as noted below, model parameters from the original calibrated model simulations provided in Attachment 2 to the above memorandum (TRC, 2013b) were used to simulate chromium reduction by CPS:

   a) Attenuation rate constants were calculated using detected baseline and Post CPS injection chromium concentrations for selected wells screened in the Upper and Lower Zones of the aquifer from various parts of the plume. The observed rate constants were used to simulate the reduction of chromium in the aquifer by CPS during the CPS reactivity duration. The geometric mean attenuation rate constants for the Upper and Lower Zones, respectively, were used to simulate chromium reductions over the time that CPS remains reactive (i.e., minimum of 5 years in the Upper Zone and 25 years in the Lower Zone). A summary of data used to derive the observed rate constants is provided as Attachment A to this analysis.

   b) Total chromium concentration data from October 2013 (post phase 2 CPS injections) were used to derive residual source concentrations for model input in response to CPS injection. Data from the following monitoring wells were used to develop residual source concentrations for the modeling scenarios of the Upper and Lower Zone of the aquifer based upon the magnitude of the chromium concentrations in these wells (see Figures 1 and 2 - attached to this analysis):
   Upper Zone: U8-A, U8-B, U8-C, U8-E, and SC-2I; and
   Lower Zone: LPW-8, LPW-9, L7-A2, L7-B2, L7-C2, L7-D2, L7-E2, SC-18D, and SC-21D.

   Based upon these data, the following, the following line source dimension and concentrations were used in the model.

Zone	Source Width (ft)	Concentration (mg/L)	Basis
Upper Zone	35[(1)]	0.05	Inferred average between ND and 0.1 mg/L contour
	84[(1)]	0.55	Inferred average between 0.1 and 1 mg/L contour
	110	2.5	Average estimated concentration inside 1 mg/L contours including U8-A and U8-B
Lower Zone	42[(1)]	0.05	Inferred average between ND and 0.1 mg/L contour
	60[(1)]	0.3	Inferred average between 0.1 and 0.5 mg/L contour
	192	6.486	Average concentration above 0.5 mg/L in wells LPW-8, LPW-9, L7-A2, L7-B2 and L7-C2.

(1) - the model doubles this width as this dimension represents one side of symmetric plume.

   c) For the Lower Zone, the target mass used in the calibrated model were further reduced by ~ 12% to account for CPS injections planned for summer 2014.

   d) Model simulations were performed for a duration equal to the CPS reactivity period (t_{CPS}).

2. The predicted chromium concentrations and mass remaining at the end of the CPS reacitivity period were used as the starting mass and source concentrations for additional BIOSCREEN simulations to evaluate the time to further reduce chromium concentrations to the 70 µg/L NJDEP criterion through MNA (t_{MNA}). The remaining model parameters from the original calibrated model simulations for conditions prior to CPS injection and described in the May 28, 2013 MNA modeling memorandum (TRC, 2013b) were used including the MNA bulk attenuation factor. The time for each simulation was extended until the predicted concentrations throughout the plume including at the source were below the NJDEP GWQS. The total remediation time for the combined ISR and MNA (tc) is equal to the sum of CPS reactivity period (5 years for the Upper Zone and 25 years for Lower zone) and the duration to achieve the NJDEP GWQS of 70 µg/l via MNA only (t_{MNA}). Model simulations are included as Attachment B to this analysis and results of the simulations are summarized below.

Estimate of Time to Reduce Chromium to 70 ug/L in Groundwater through Groundwater Extraction vs. CPS Injection and MNA
Shieldalloy Site
Newfield, NJ

Calculation By: JSH
Checked By: NMR

Simulation	CPS Reactivity Period, t_{CPS} (Years)	Duration to reach NJDEP GWQS via MNA post CPS Reactivity Period, t_{MNA} (Years)	Total ISR & MNA Duration (time to achieve NJDEP GWQS via ISR & MNA) , $t_c^{(*)}$ (Years)
Upper Plume			
Farm Parcel			
4a (0.75 ppm)	5	117	122
4aR1 (0.75 ppm)	5	133	138
5aR1 (0.75 ppm	5	111	116
Lower Plume			
Farm Parcel			
5 (1.25 ppm)	25	287	312
6 (1.25 ppm)	25	272	297
7 (1.25 ppm)	25	223	248

(*) $t_c = t_{CPS} + t_{MNA}$

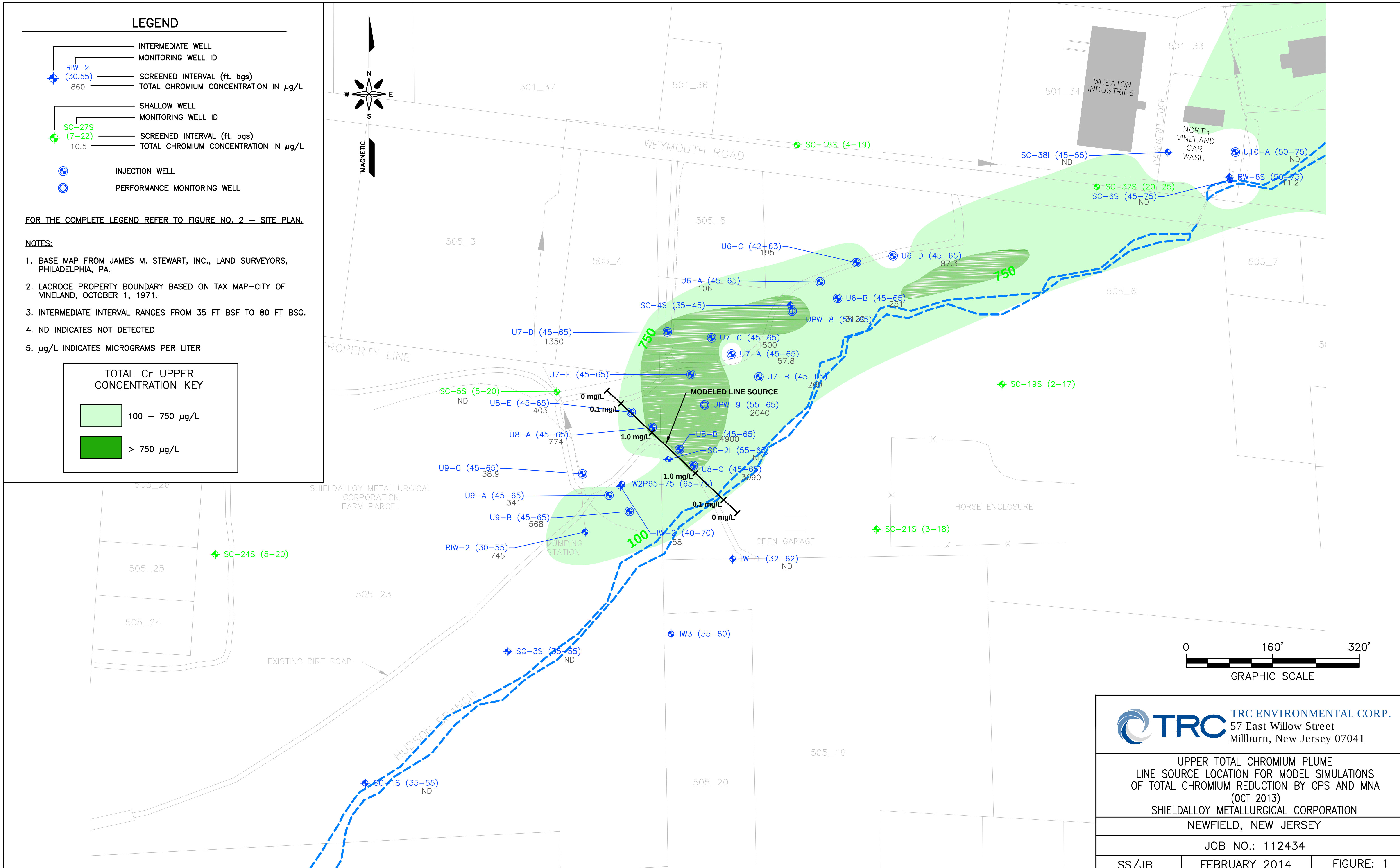
Based upon these data, the time to attain the 70 µg/l criterion within the plume via ISR and MNA is shorter than that for Pump & Treat.

References:

- Driscoll, F.A., 1986. Groundwater and Wells. The Johnson Division, St. Paul, MN
- EPA, 1988. Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites. EPA/540/G-88/003; December 1988.
- TRC, 2011. ISR Pilot Test Report & Expanded ISR Pilot Program Workplan prepared by TRC and dated February 2011
- TRC, 2013a. *EPA Procedural Assessment of MNA of Chromium in Groundwater at SMC Site* . TRC Technical Memorandum dated February 24, 2013.
- TRC, 2013b. *SMC MNA Model* . TRC Technical Memorandum dated May 28, 2013.

Appendix B

Figures



FILE: C:\USERS\MDRAFT\DESKTOP\4A_4B – UPPER TOTAL CHROME PLUME 10_2013_REV2_750__TM.DWG 03/24/14 01:10:41PM, mdraft, LAYOUT: 4B-DETAIL

FILE: \\MILLBURN-FP2\DRAFTINGFILES\CAD FILES\WORK\2710ES\2014_03 ISR EVALUATION REPORT\6A_6B – LOWER TOTAL CHROME PLUME 10_2013 REV2_1250__TM.DWG 03/31/14 01:46:20PM, mdraft, LAYOUT: 6B-DETAIL

Appendix B

Attachments

ATTACHMENT A

CALCULATION OF CHROMIUM RATE CONSTANTS

Estimation of Cr Rate Constants
from CPS Reduction
Shield Alloy Site
Newfields, New Jersey

Problem Statement

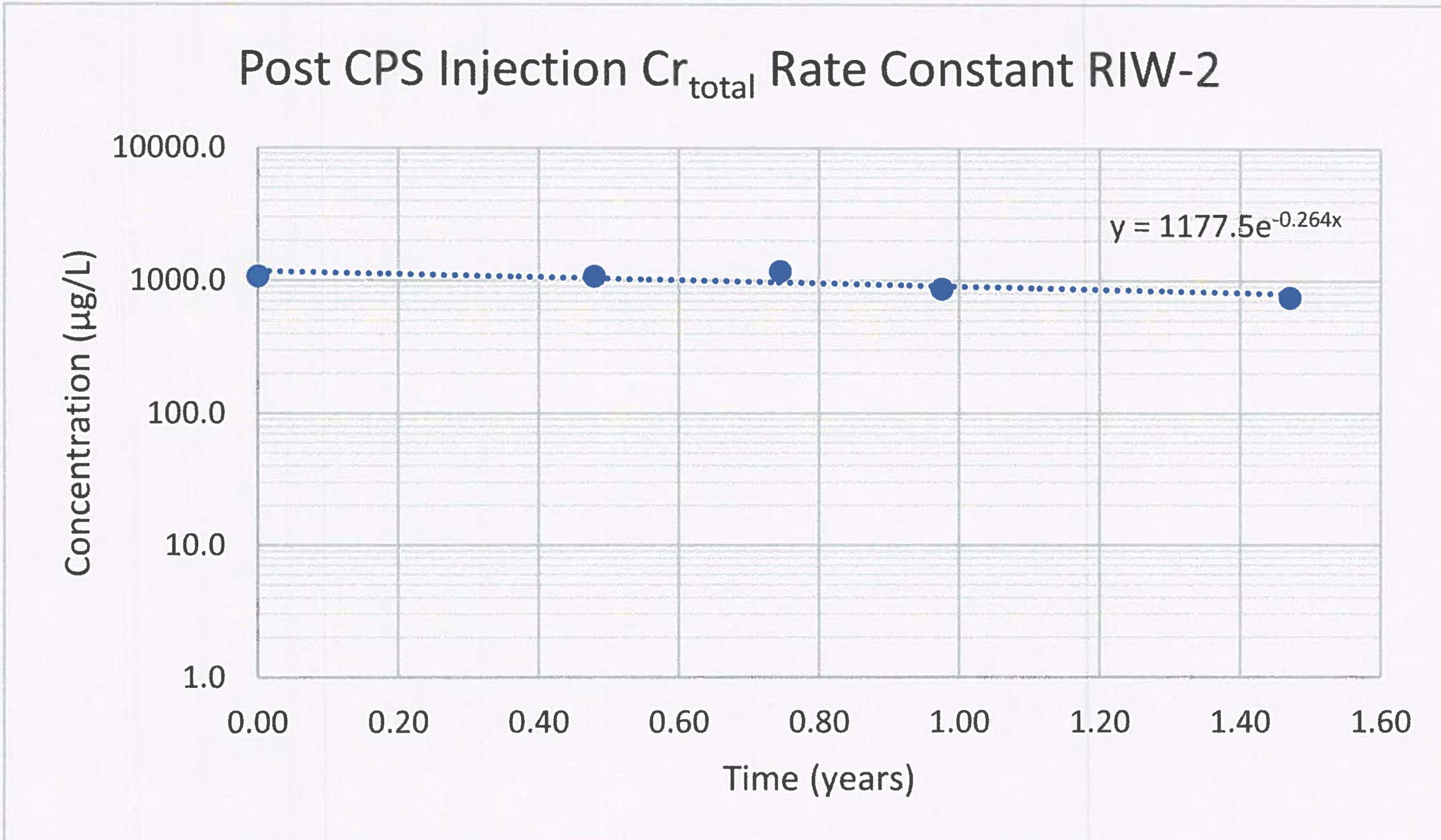
Estimate the average decay rate constant for reduction of total chromium due to in-situ reduction by Calcium Polysulfide Injections using baseline and post-injection analytical data obtained from wells screened within the footprint of the total chromium plume.

Use the procedure described in EPA Groundwater Issue - Calculation and Use of First Order Rate Constants for Monitored Natural Attenuation by Newell et. Al. for decay rate constant.

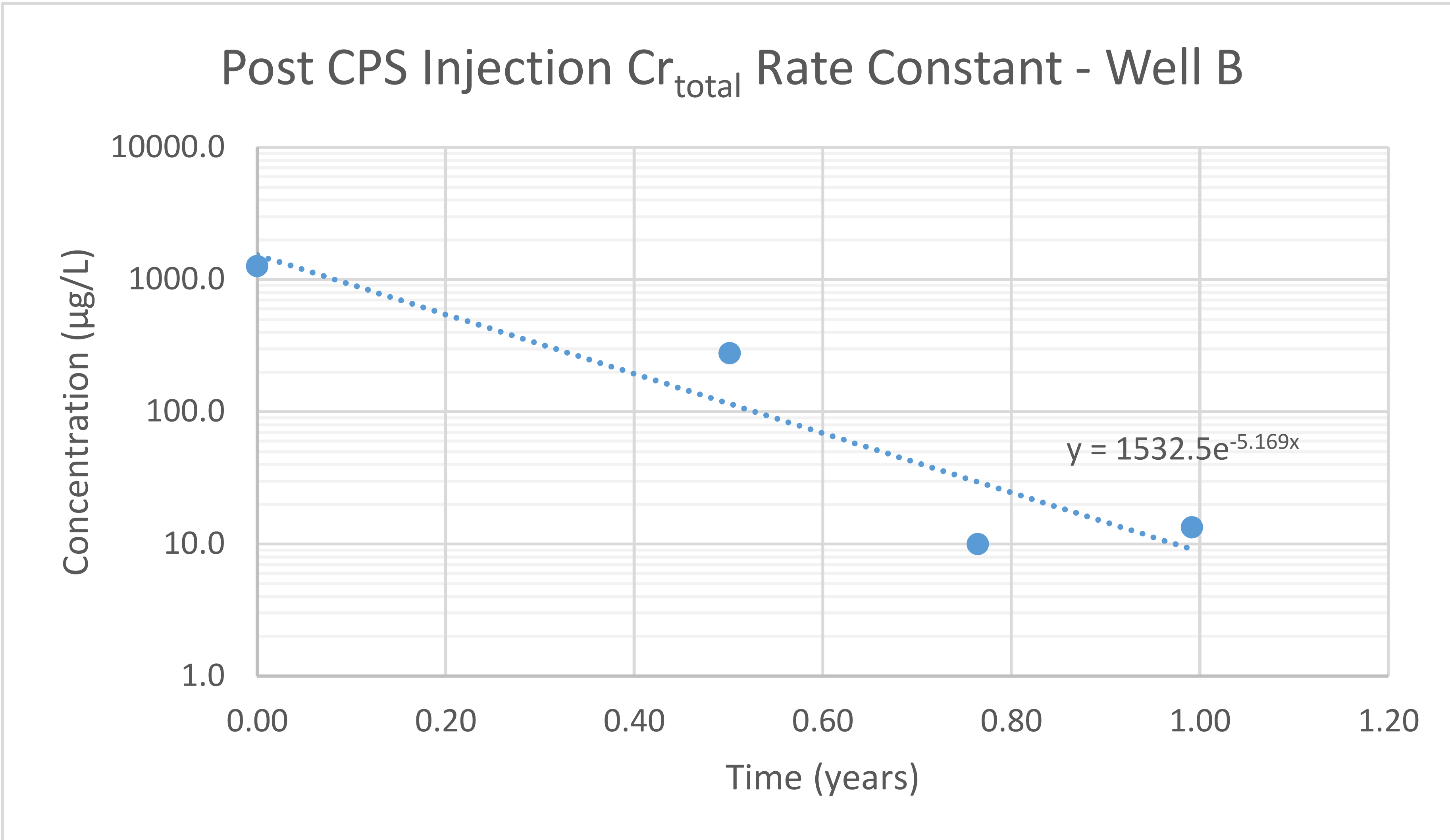
Upper Zone

Monitoring Well	Date	Approximate Elapsed Time (days)	Approximate Elapsed Time (yrs)	Concentration (µg/L)	Rate Constant (per year)
RIW-2	May-12	0	0.00	1070.0	
	Oct-12	175	0.48	1070.0	
	Jan-13	272	0.75	1170.0	0.26
	Apr-13	356	0.98	860.0	
	Oct-13	537	1.47	745.0	
B	Apr-12	0	0.00	1270.0	
	Oct-12	183	0.50	277.0	5.17
	Jan-13	279	0.76	10.0	
	Apr-13	362	0.99	13.4	
SC-2I	May-12	0	0.00	2470.0	
	Nov-12	180	0.49	1170.0	
	Jan-13	235	0.64	405.0	3.18
	Apr-13	342	0.94	139.0	
	Jan-14	626	1.72	13.5	
U6-A	Aug-12	0	0.00	5000.0	
	Nov-12	98	0.27	793.0	3.25
	Apr-13	257	0.70	56.6	
	Oct-13	444	1.22	106.0	
U7-A	Apr-12	0	0.00	3550.0	
	Oct-12	160	0.44	937.0	
	Jul-13	457	1.25	519.0	2.37
	Oct-13	542	1.48	57.8	
	Jan-14	637	1.75	47.6	
U7-B	Apr-12	0	0.00	8310.0	
	Nov-12	193	0.53	433.0	
	Apr-13	351	0.96	284.0	2.24
	Aug-13	458	1.25	73.3	
	Oct-13	540	1.48	269.0	
	Jan-14	638	1.75	108.0	
U9-B	Jul-12	0	0.00	8330.0	
	Nov-12	120	0.33	811.0	
	Jan-13	202	0.55	776.0	1.84
	Apr-13	279	0.76	490.0	
	Oct-13	467	1.28	568.0	
UPW-9	Jan-13	0	0.00	9160.0	
	Apr-13	107	0.29	6360.0	1.87
	Oct-13	300	0.82	2040.0	

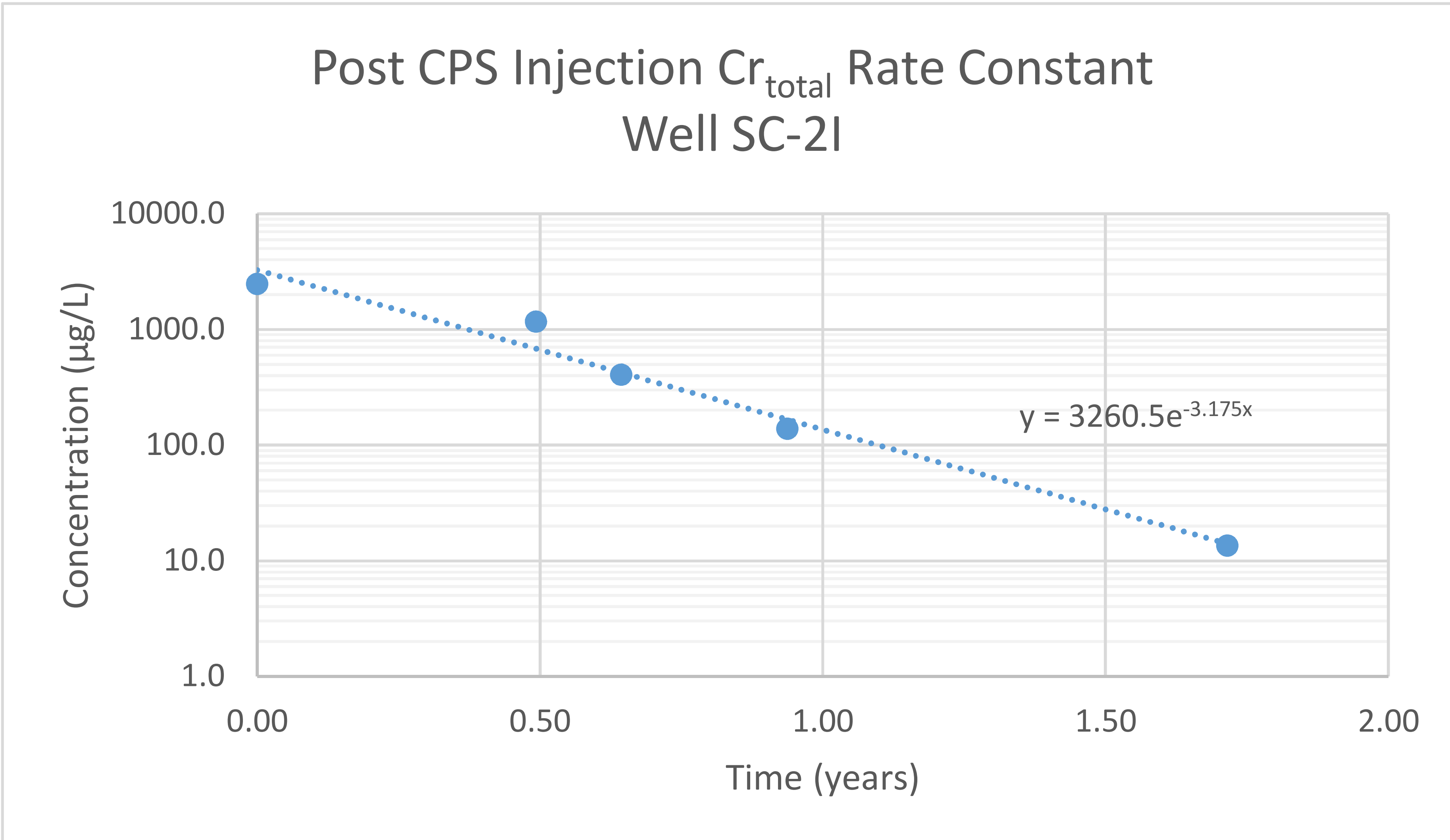
Geomean 2.00

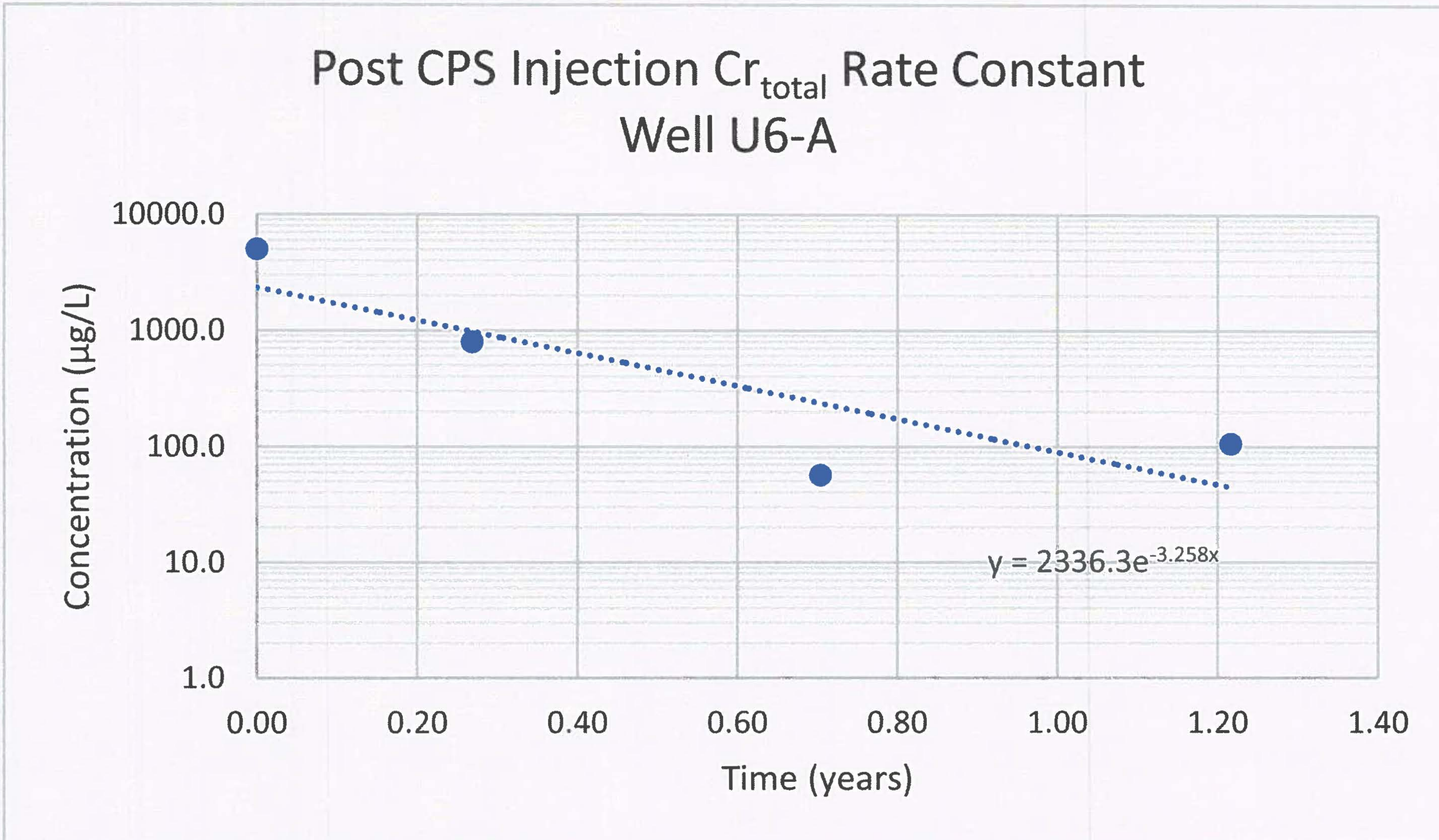


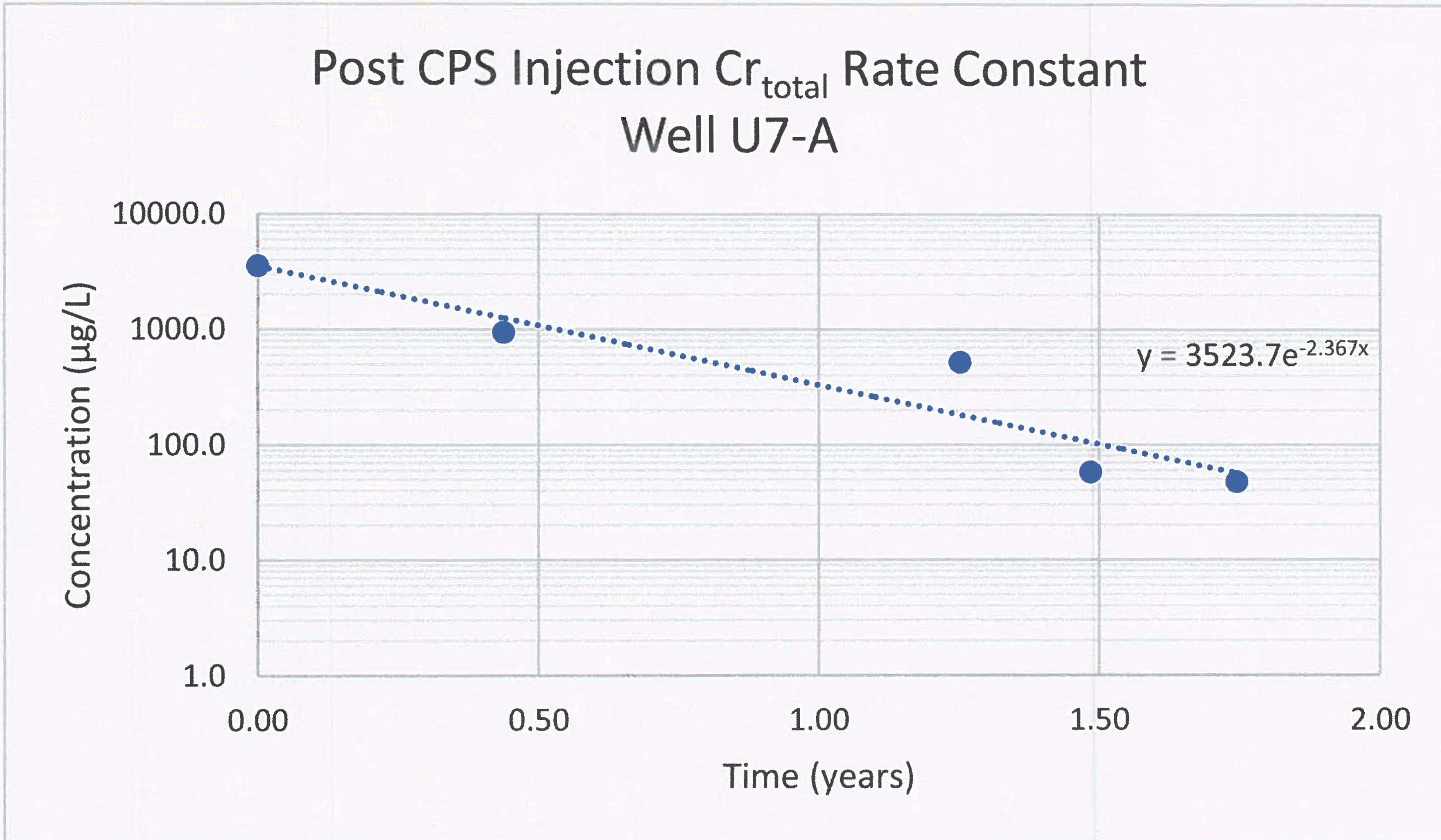
Post CPS Injection Cr$_{total}$ Rate Constant RIW-2
y = 1177.5e$^{-0.264x}$
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Time (years)



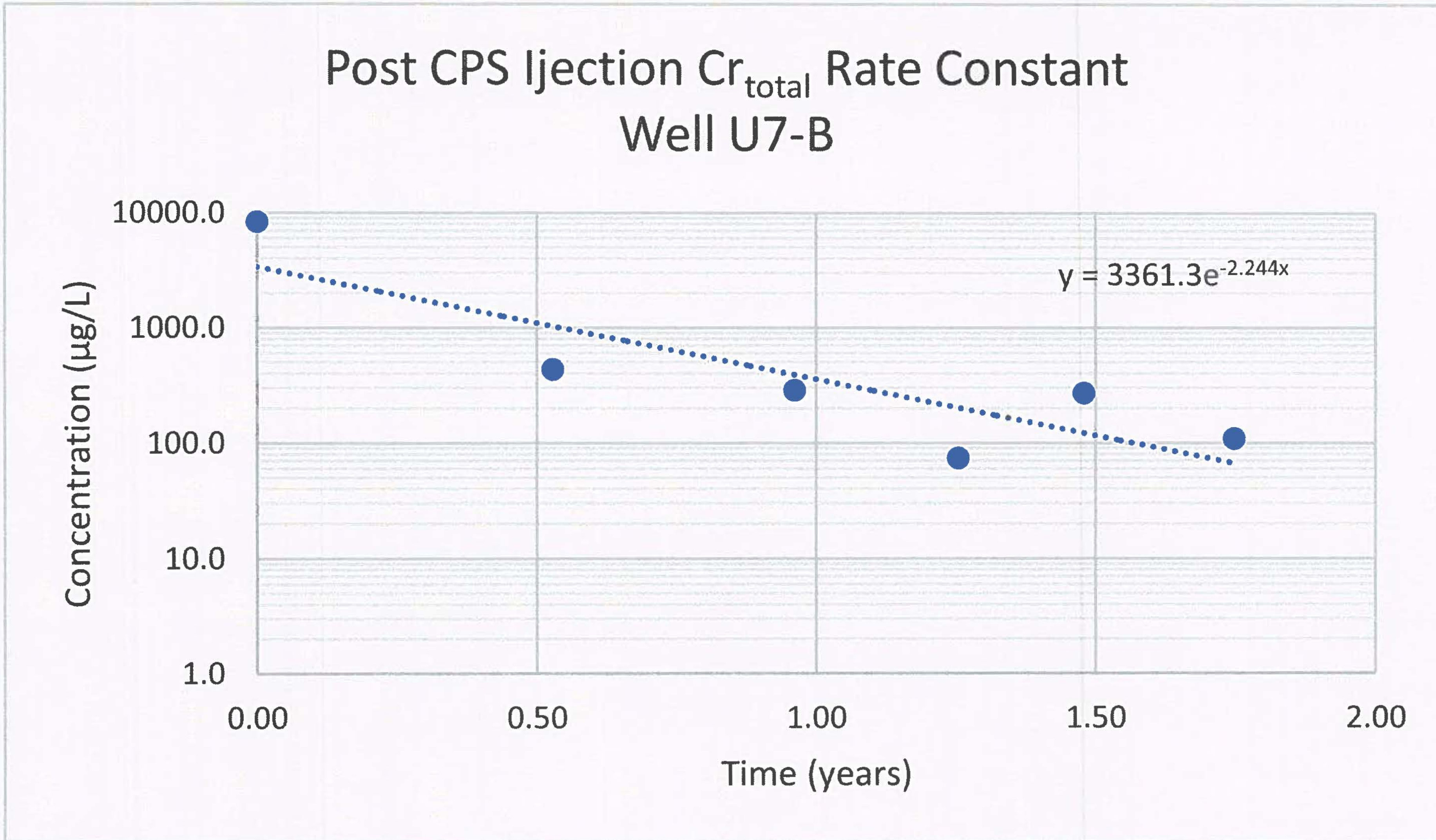
Post CPS Injection Cr_total Rate Constant - Well B
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Time (years)
y = 1532.5e^-5.169x


Post CPS Injection Cr$_{total}$ Rate Constant
Well SC-2I
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.50
1.00
1.50
2.00
Time (years)
$y = 3260.5e^{-3.175x}$

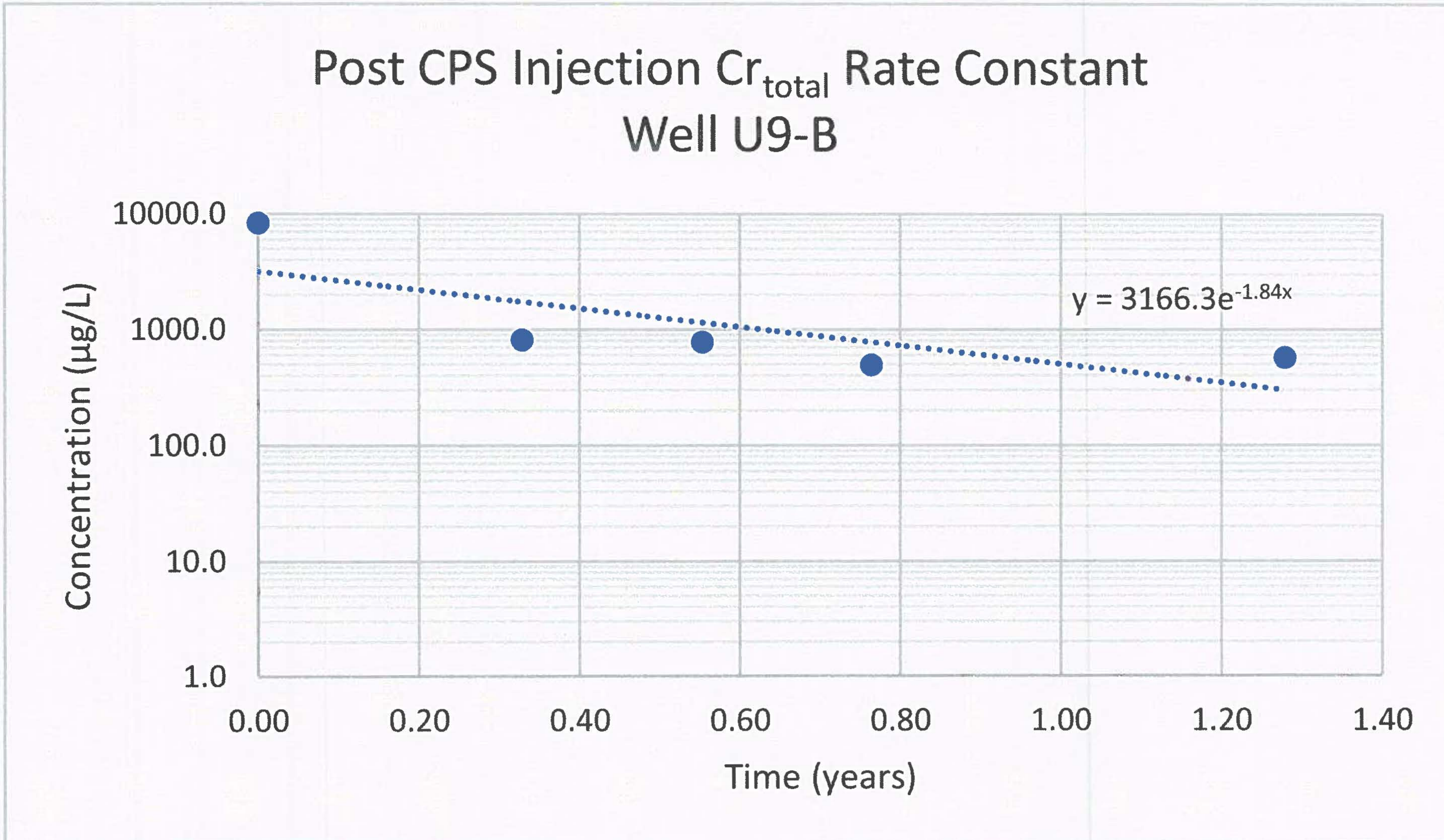

Post CPS Injection Cr_{total} Rate Constant
Well U6-A
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Time (years)
$y = 2336.3e^{-3.258x}$



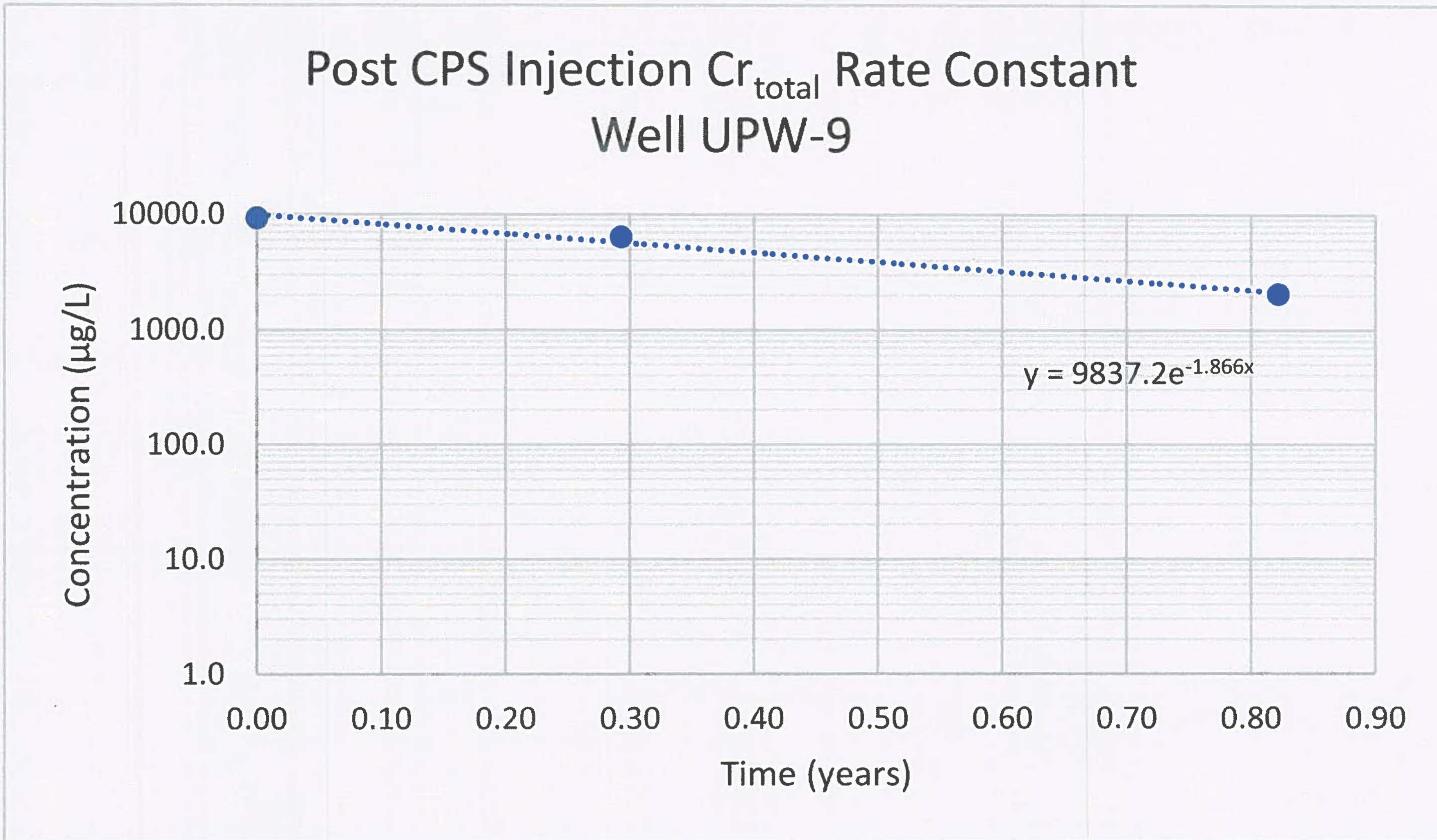
Post CPS Injection Cr$_{total}$ Rate Constant
Well U7-A
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
y = 3523.7e$^{-2.367x}$
0.00
0.50
1.00
1.50
2.00
Time (years)



Post CPS Ijection Cr$_{total}$ Rate Constant
Well U7-B
y = 3361.3e$^{-2.244x}$
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.50
1.00
1.50
2.00
Time (years)



Post CPS Injection Cr_{total} Rate Constant
Well U9-B
y = 3166.3e^{-1.84x}
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Time (years)


Post CPS Injection Cr_{total} Rate Constant
Well UPW-9
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
$y = 9837.2e^{-1.866x}$
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
Time (years)

Estimation of Cr Rate Constants
from CPS Reduction
Shield Alloy Site
Newfields, New Jersey

Problem Statement

Estimate the average decay rate constant for reduction of total chromium due to in-situ reduction by Calcium Polysulfide Injections using baseline and post-injection analytical data obtained from wells screened within the footprint of the total chromium plume.

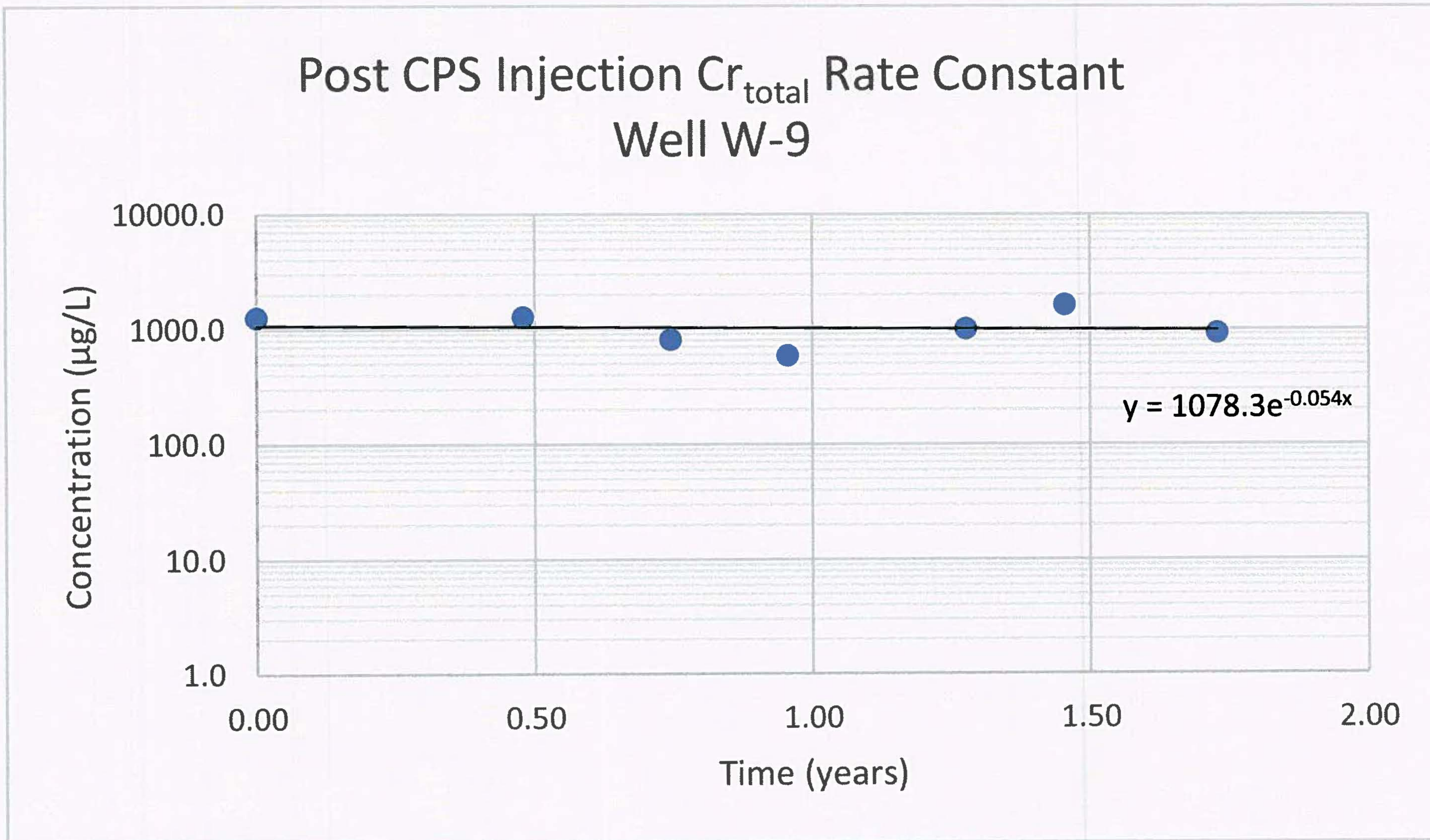
Use the procedure described in EPA Groundwater Issue - Calculation and Use of First Order Rate Constants for Monitored Natural Attenuation by Newell et. Al. for decay rate constant.

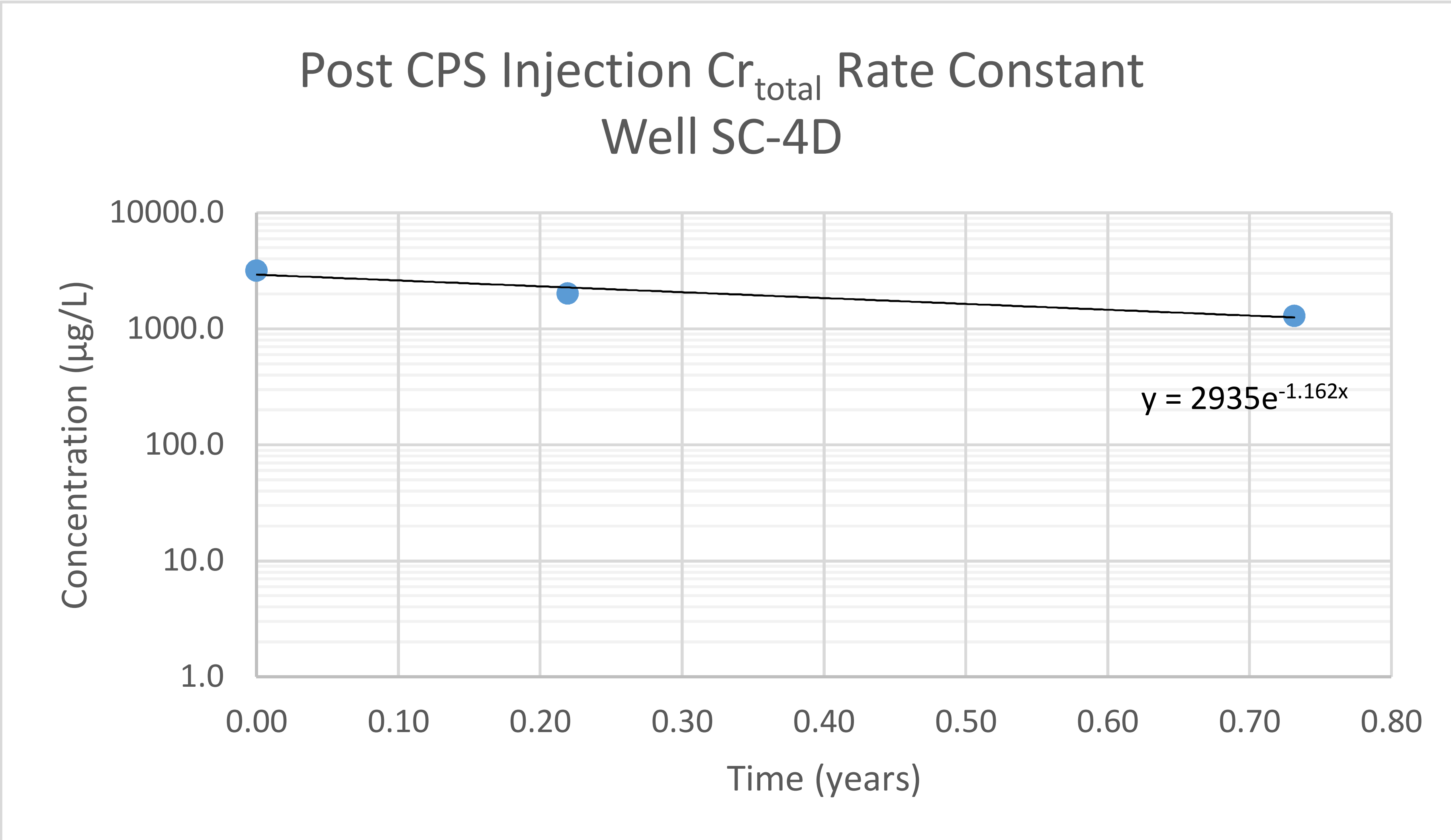
Lower Zone

Monitoring Well	Date	Approximate Elapsed Time (days)	Approximate Elapsed Time (yrs)	Concentration (µg/L)	Rate Constant (per year)
W-9	May-12	0	0.00	1270.0	
	Oct-12	175	0.48	1280.0	
	Jan-13	272	0.75	815.0	
	Apr-13	349	0.96	588.0	0.054
	Aug-13	466	1.28	1010.0	
	Oct-13	531	1.45	1630.0	
	Jan-14	631	1.73	926.0	
SC-4D	Jan-13	0	0.00	3190.0	
	Apr-13	80	0.22	2020.0	1.16
	Oct-13	267	0.73	1300.0	
SC-2D(R)	Jan-13	0	0.00	1800.0	
	Apr-13	79	0.22	1390.0	
	Jul-13	181	0.50	16.0	3.2
	Oct-13	258	0.71	41.9	
	Jan-14	362	0.99	199.0	
MWH-4	Apr-12	0	0.00	5280.0	
	Oct-12	181	0.50	3930.0	
	Jan-13	280	0.77	2120.0	
	Apr-13	362	0.99	2250.0	0.43
	Aug-13	464	1.27	2100.0	
	Oct-13	541	1.48	1980.0	
	Jan-14	639	1.75	3000.0	
IWC-5	Apr-12	0	0.00	342.0	
	Apr-13	363	0.99	190.0	1.02
	Oct-13	541	1.48	68.0	
LPW-9	Nov-12	0	0.00	14400.0	
	Jan-13	84	0.23	14700.0	0.27
	Apr-13	162	0.44	13100.0	
	Oct-13	353	0.97	11400.0	

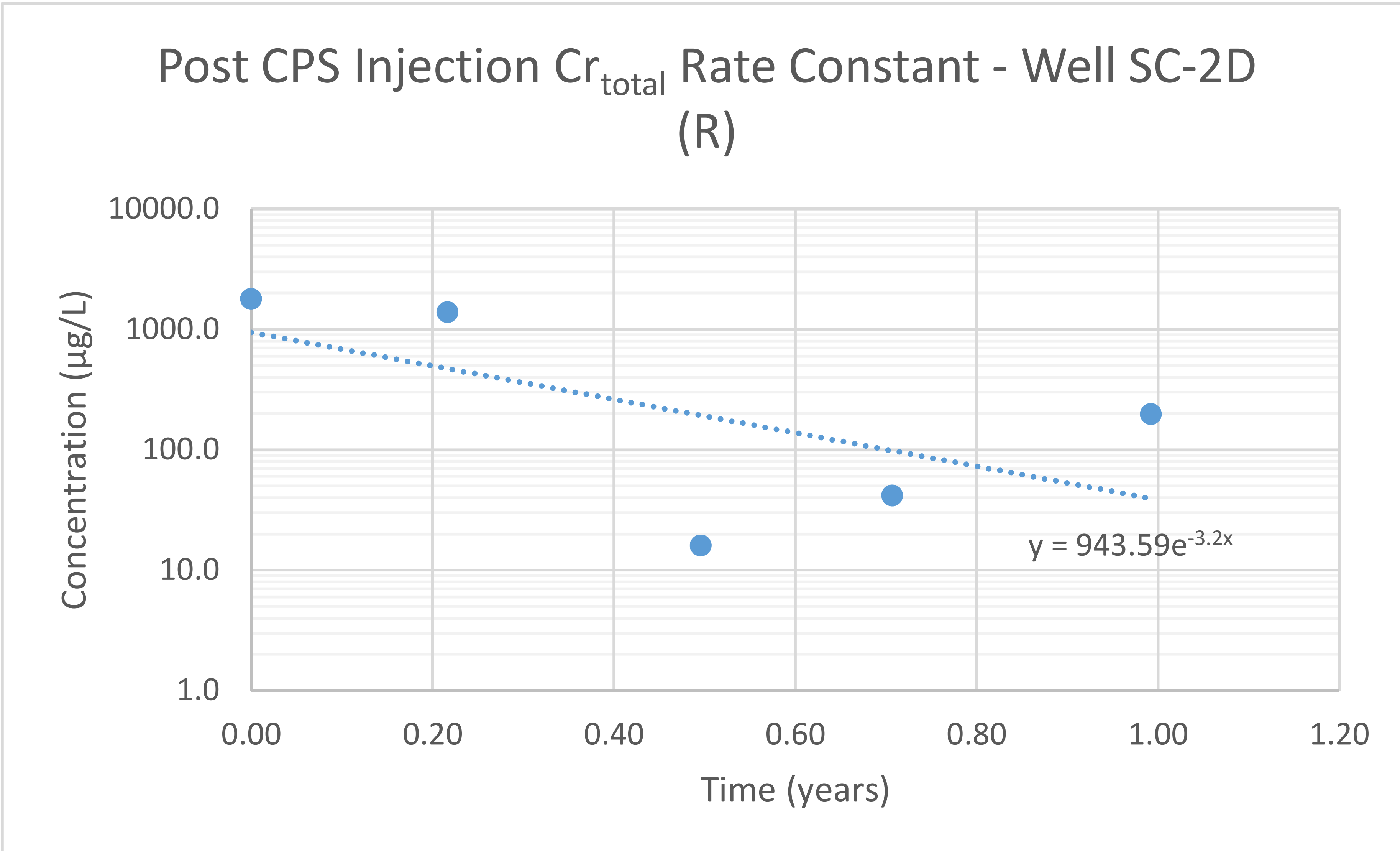
Estimation of Cr Rate Constants
from CPS Reduction
Shield Alloy Site
Newfields, New Jersey

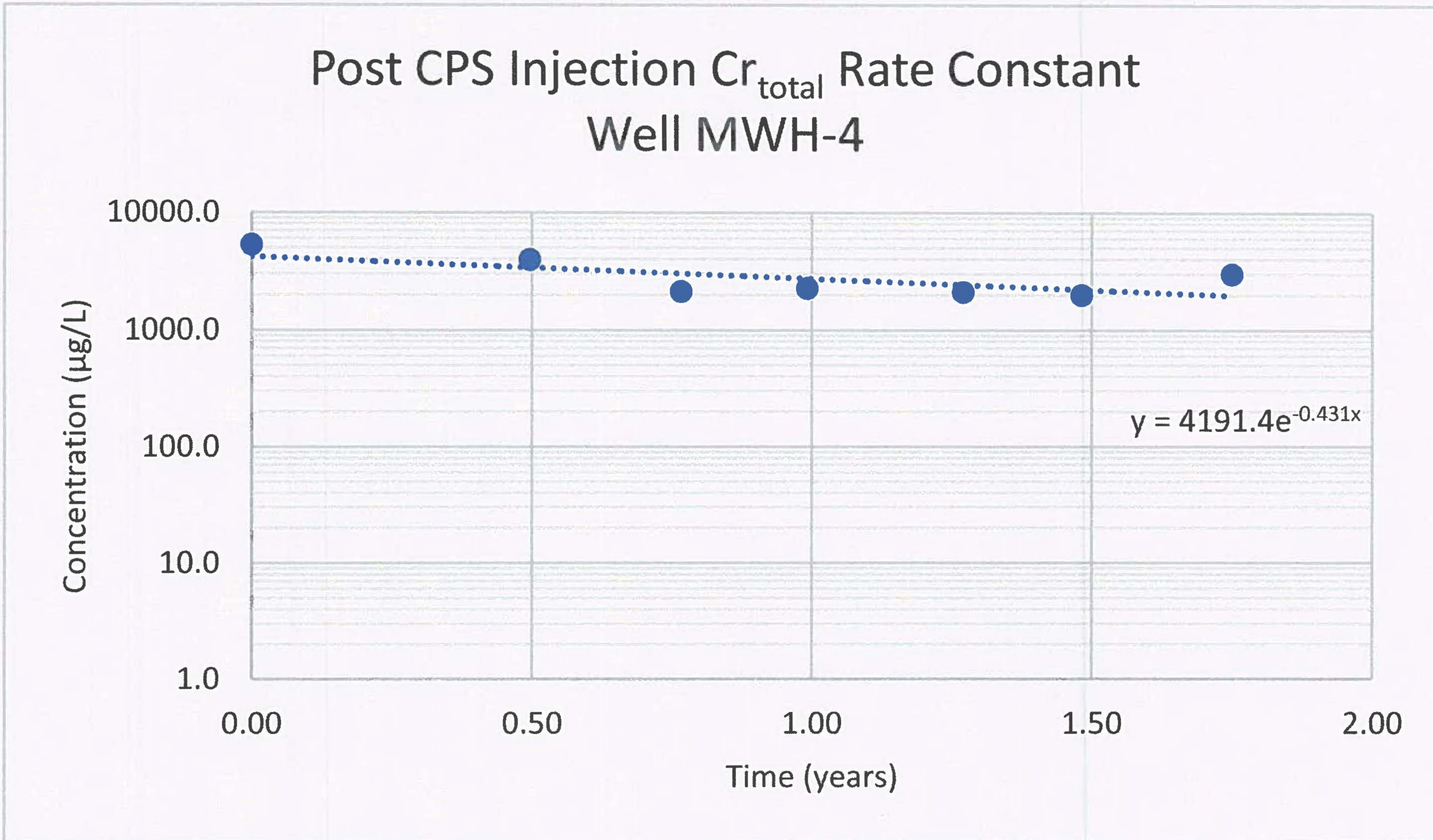
Monitoring Well	Date	Approximate Elapsed Time (days)	Approximate Elapsed Time (yrs)	Concentration (µg/L)	Rate Constant (per year)
L6-B1	Aug-12	0	0.00	2790.0	
	Nov-12	97	0.27	1980.0	
	Jan-13	179	0.49	685.0	1.78
	Apr-13	258	0.71	417.0	
	Oct-13	448	1.23	373.0	
L6-B2	Aug-12	0	0.00	2010.0	
	Nov-12	97	0.27	647.0	1.72
	Apr-13	258	0.71	246.0	
	Oct-13	446	1.22	229.0	
L7-B1	Aug-12	0	0.00	8850.0	
	Nov-12	99	0.27	6330.0	
	Jan-13	180	0.49	206.0	1.52
	Apr-13	259	0.71	918.0	
	Oct-13	443	1.21	1610.0	
L7-C1	Aug-12	0	0.00	12600.0	
	Nov-12	100	0.27	2820.0	
	Jan-13	180	0.49	1320.0	2.45
	Apr-13	258	0.71	671.0	
	Oct-13	446	1.22	574.0	
L7-E2	Aug-12	0	0.00	3400.0	
	Nov-12	84	0.23	4410.0	
	Jan-13	165	0.45	1020.0	
	Apr-13	244	0.67	127.0	1.65
	Aug-13	351	0.96	361.0	
	Oct-13	427	1.17	487.0	
	Jan-14	526	1.44	463.0	
L9-B1	Jul-12	0	0.00	12100.0	
	Nov-12	121	0.33	648.0	3.59
	Apr-13	283	0.78	61.3	
	Oct-13	468	1.28	118.0	
L9-D1	Nov-12	0	0.00	607.0	
	Apr-13	160	0.44	491.0	2.04
	Oct-13	348	0.95	90.1	
				Geomean	1.10

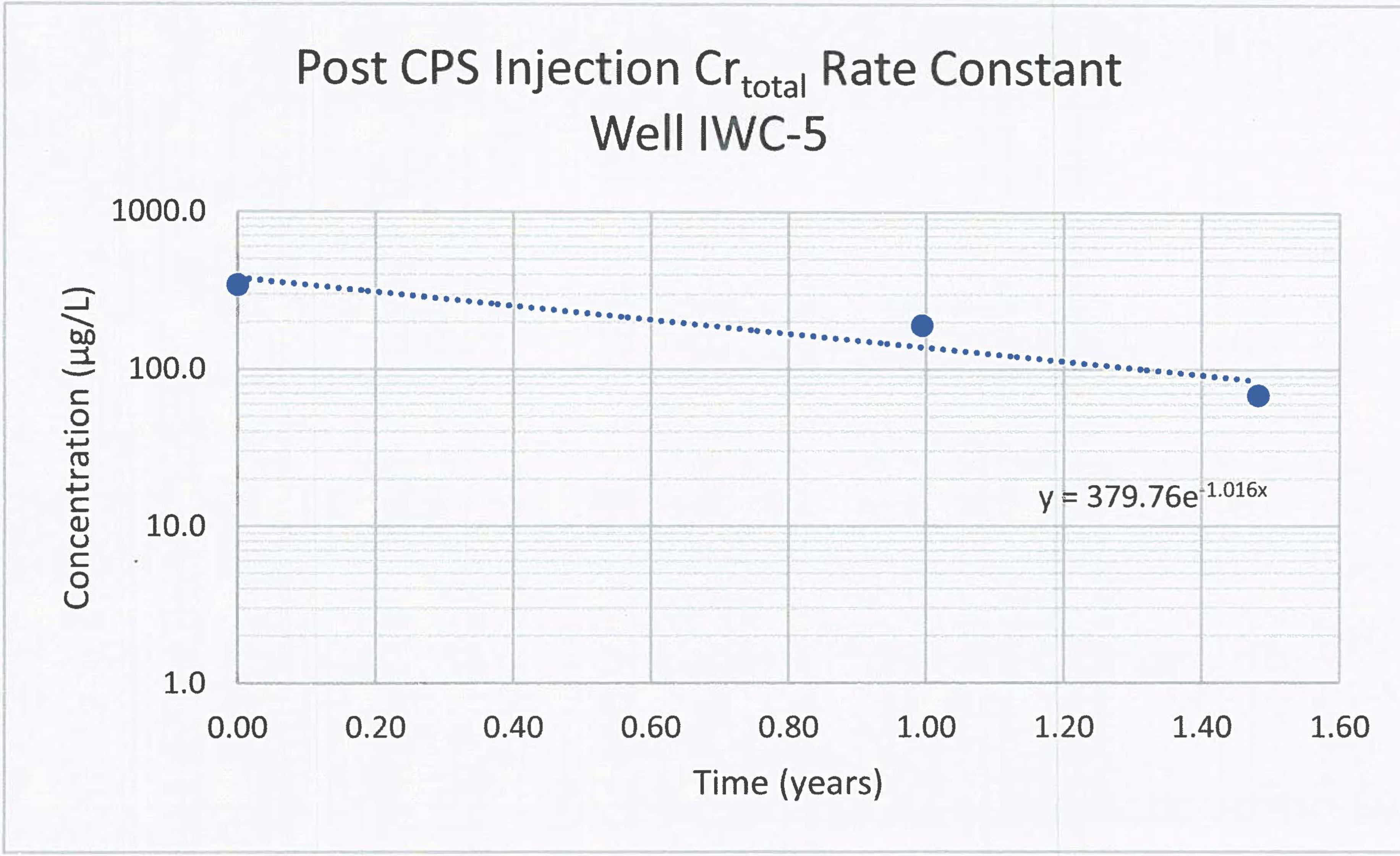

Post CPS Injection Cr$_{total}$ Rate Constant
Well W-9
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
$y = 1078.3e^{-0.054x}$
0.00
0.50
1.00
1.50
2.00
Time (years)

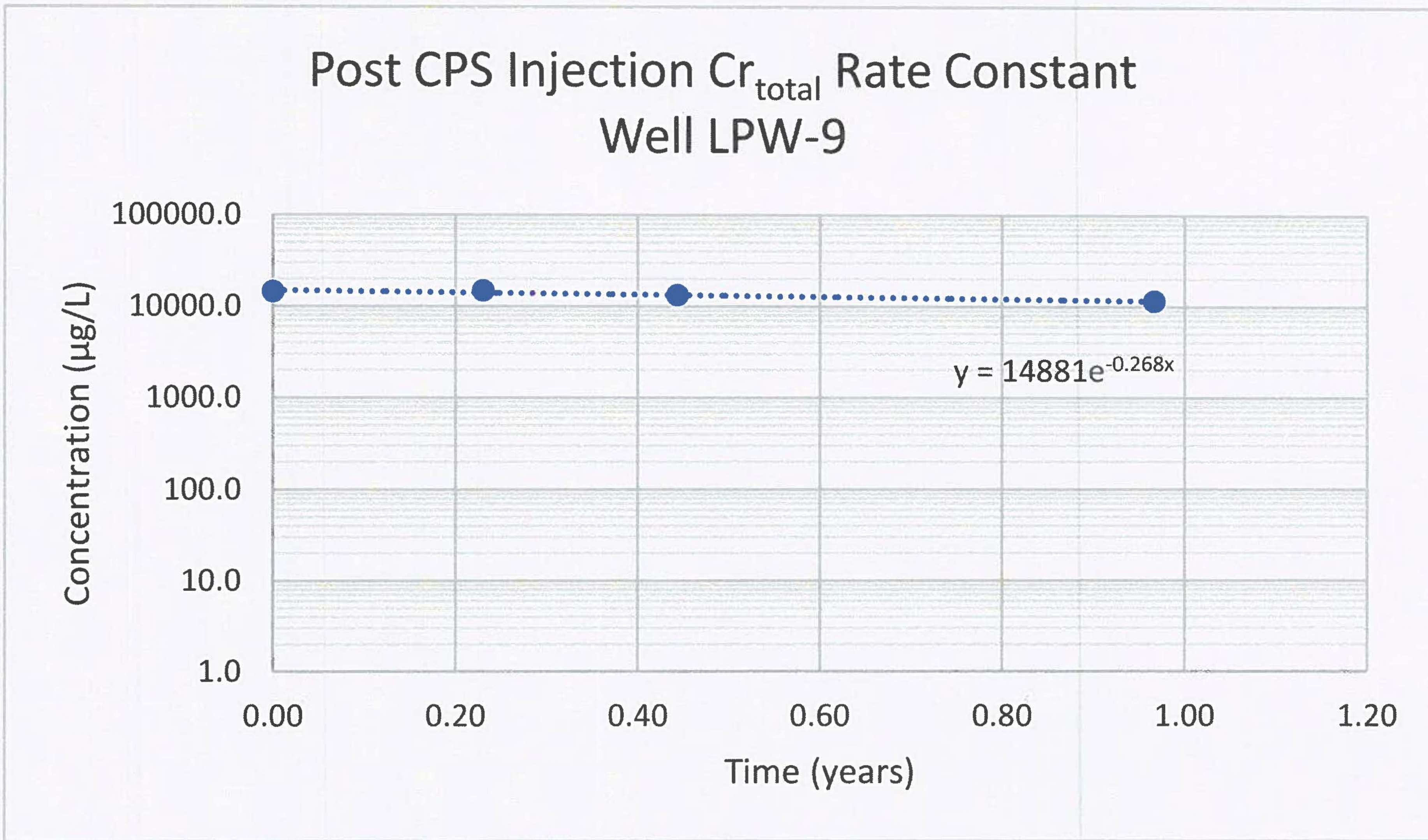


Post CPS Injection Cr_{total} Rate Constant
Well SC-4D
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
$y = 2935e^{-1.162x}$
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Time (years)

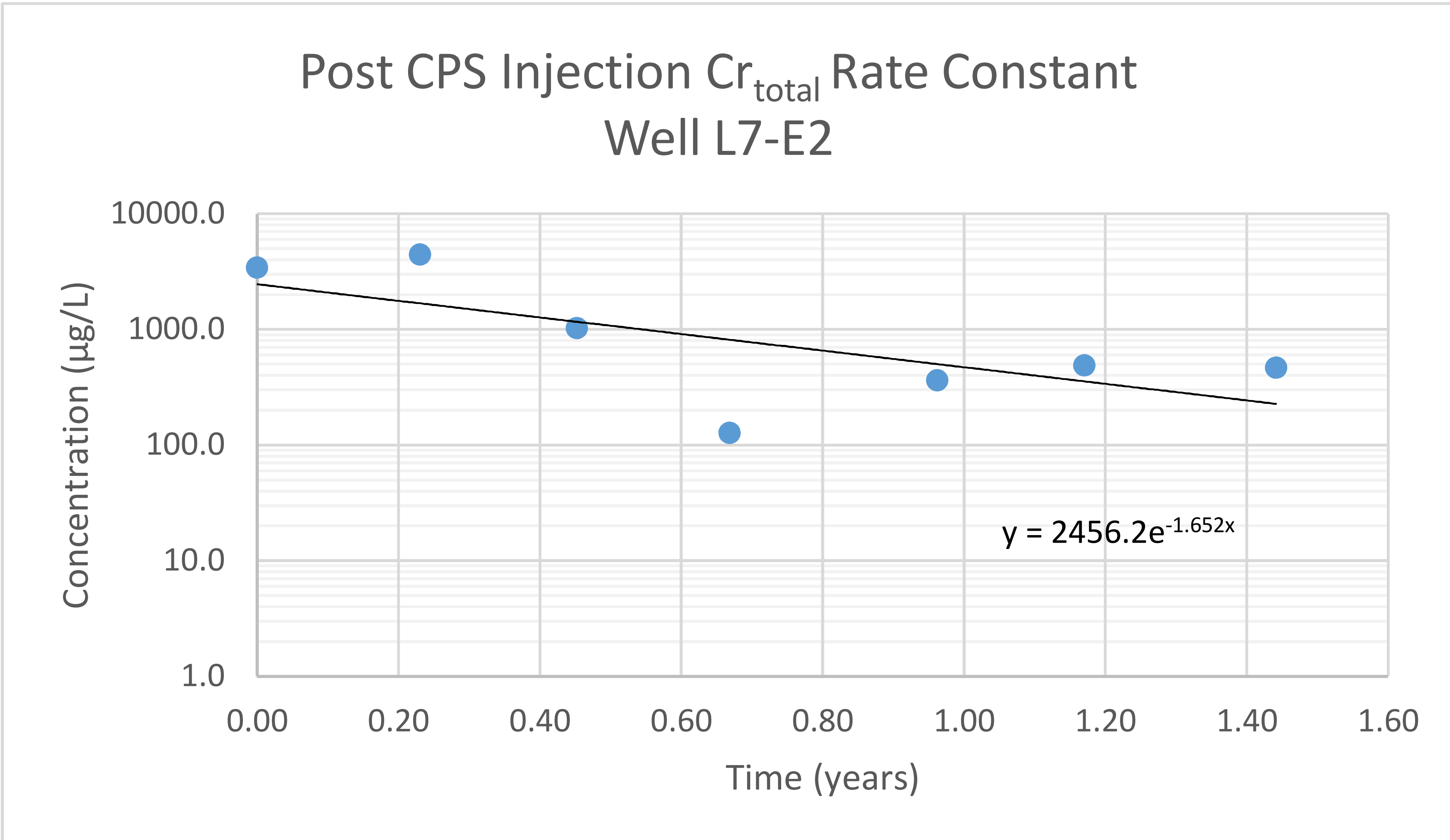

Post CPS Injection Cr total Rate Constant - Well SC-2D (R)
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Time (years)
y = 943.59e-3.2x


Post CPS Injection Cr$_{total}$ Rate Constant
Well MWH-4
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
$y = 4191.4e^{-0.431x}$
0.00
0.50
1.00
1.50
2.00
Time (years)

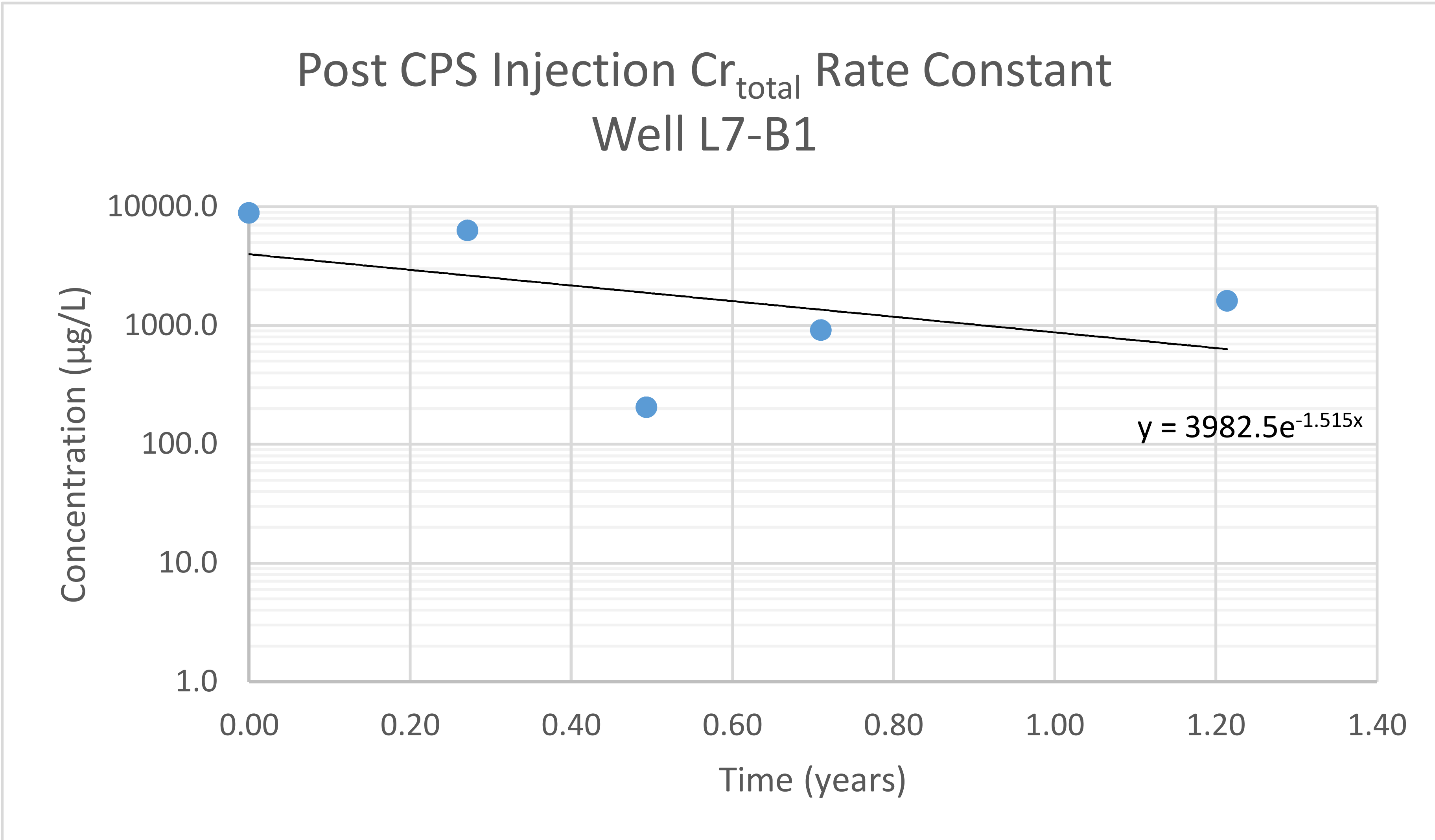

Post CPS Injection Cr$_{total}$ Rate Constant
Well IWC-5
1000.0
100.0
10.0
1.0
Concentration (µg/L)
$y = 379.76e^{-1.016x}$
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Time (years)

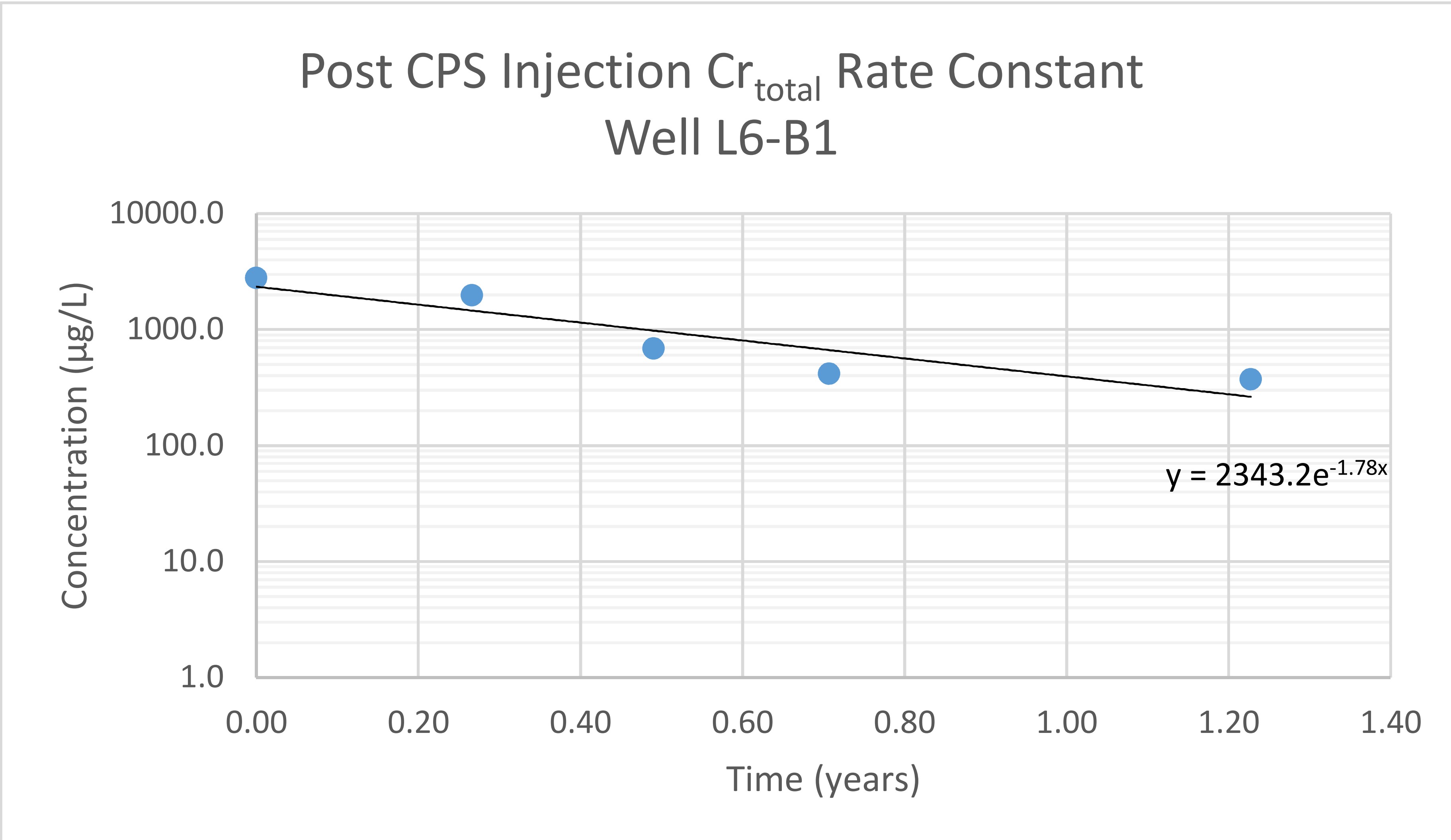


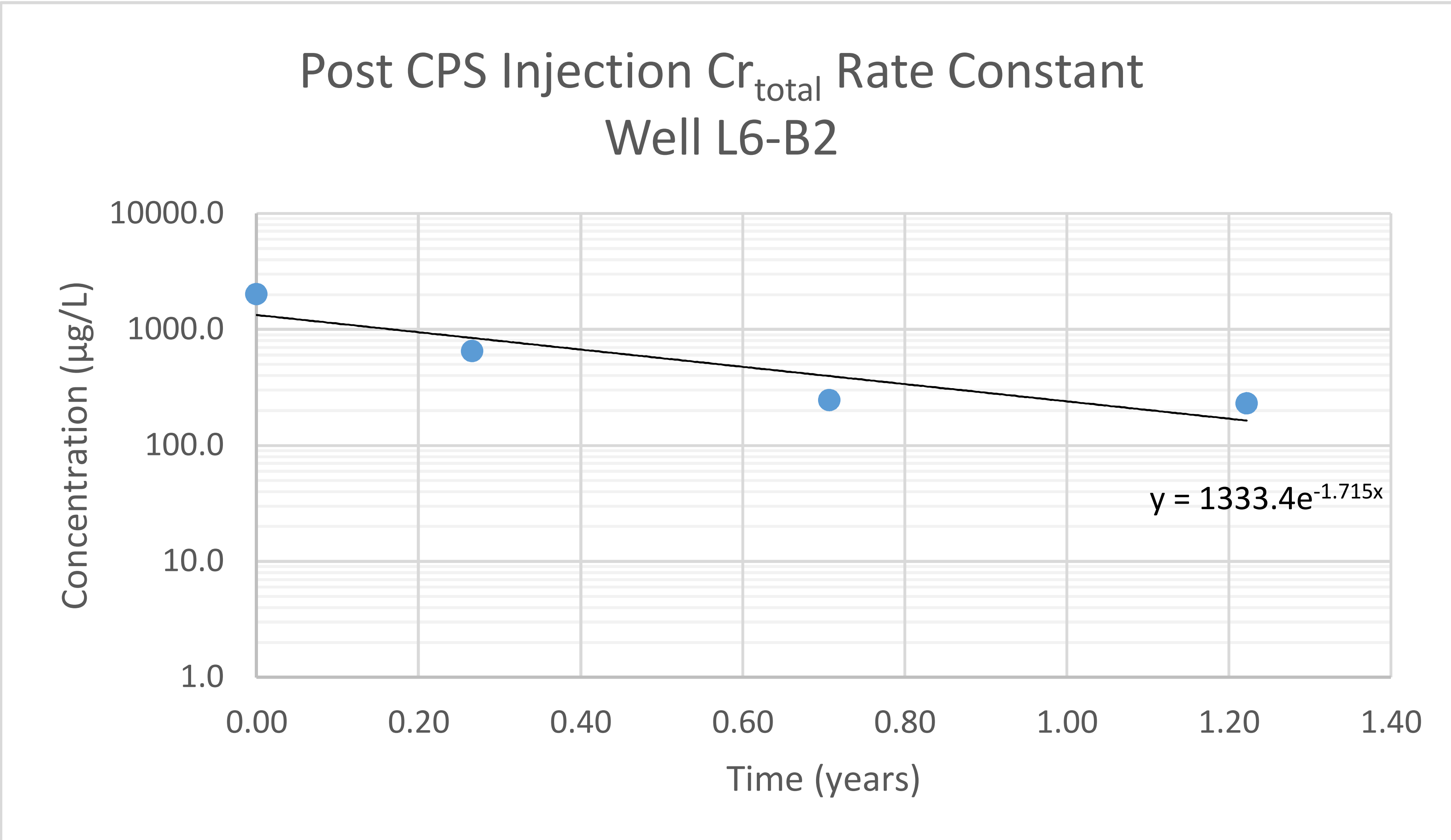
Post CPS Injection Cr total Rate Constant
Well LPW-9
100000.0
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
y = 14881e-0.268x
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Time (years)



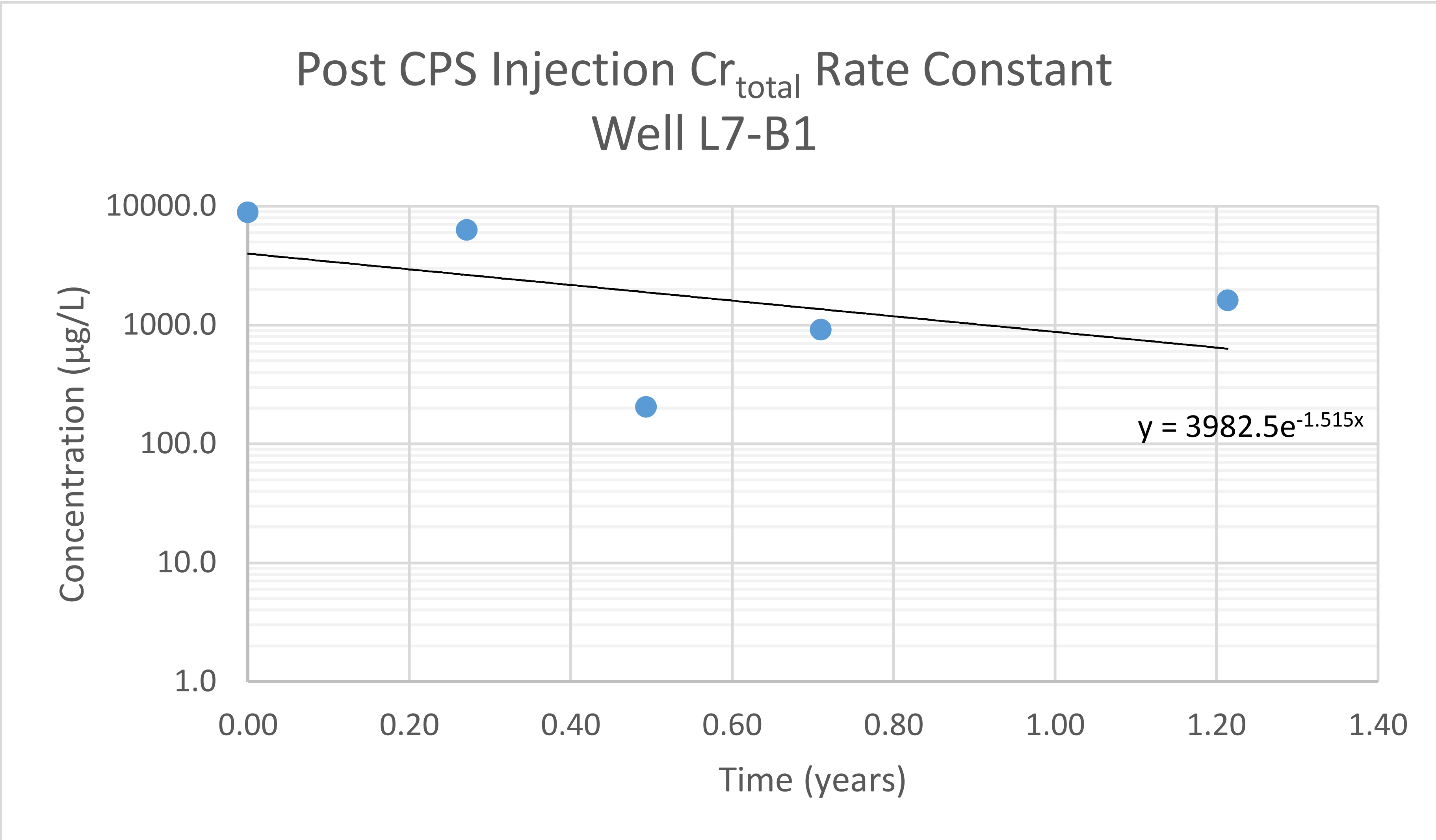
Post CPS Injection Cr_{total} Rate Constant
Well L7-E2
Concentration (µg/L)
10000.0
1000.0
100.0
10.0
1.0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
Time (years)
$y = 2456.2e^{-1.652x}$


Post CPS Injection Cr$_{total}$ Rate Constant
Well L7-B1
Concentration (µg/L)
10000.0
1000.0
100.0
10.0
1.0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Time (years)
$y = 3982.5e^{-1.515x}$

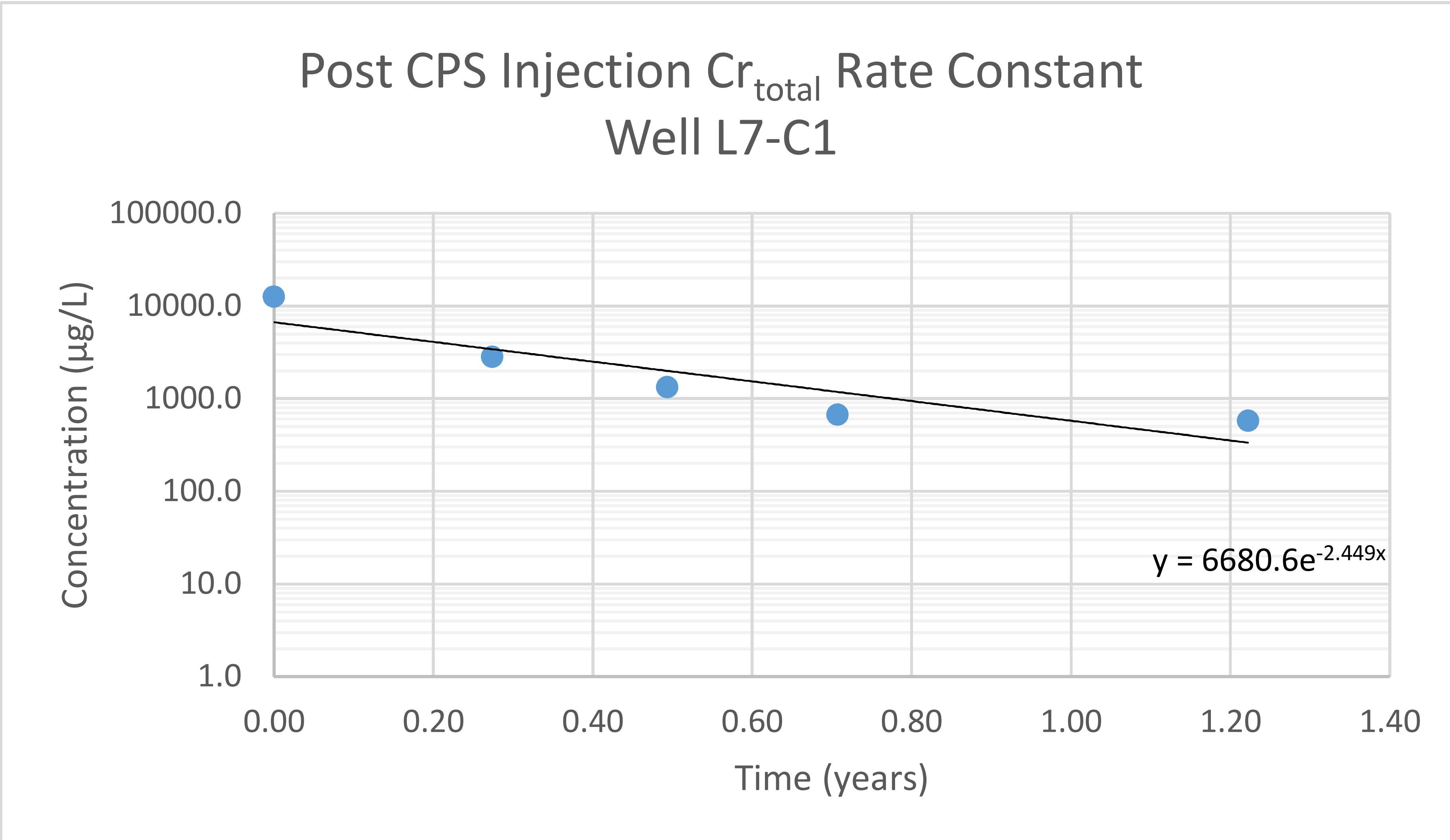

Post CPS Injection Cr$_{total}$ Rate Constant
Well L6-B1
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Time (years)
$y = 2343.2e^{-1.78x}$

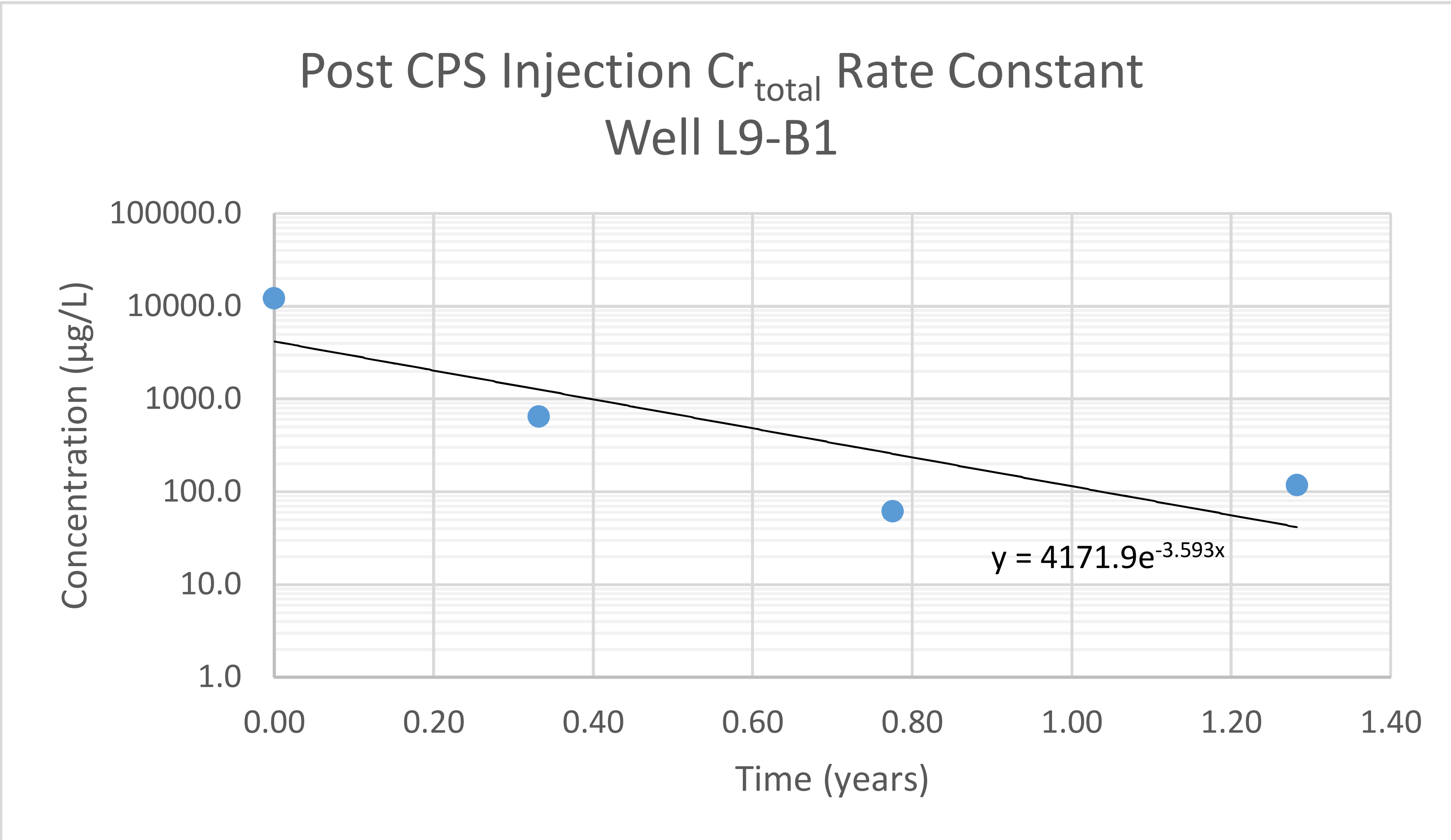


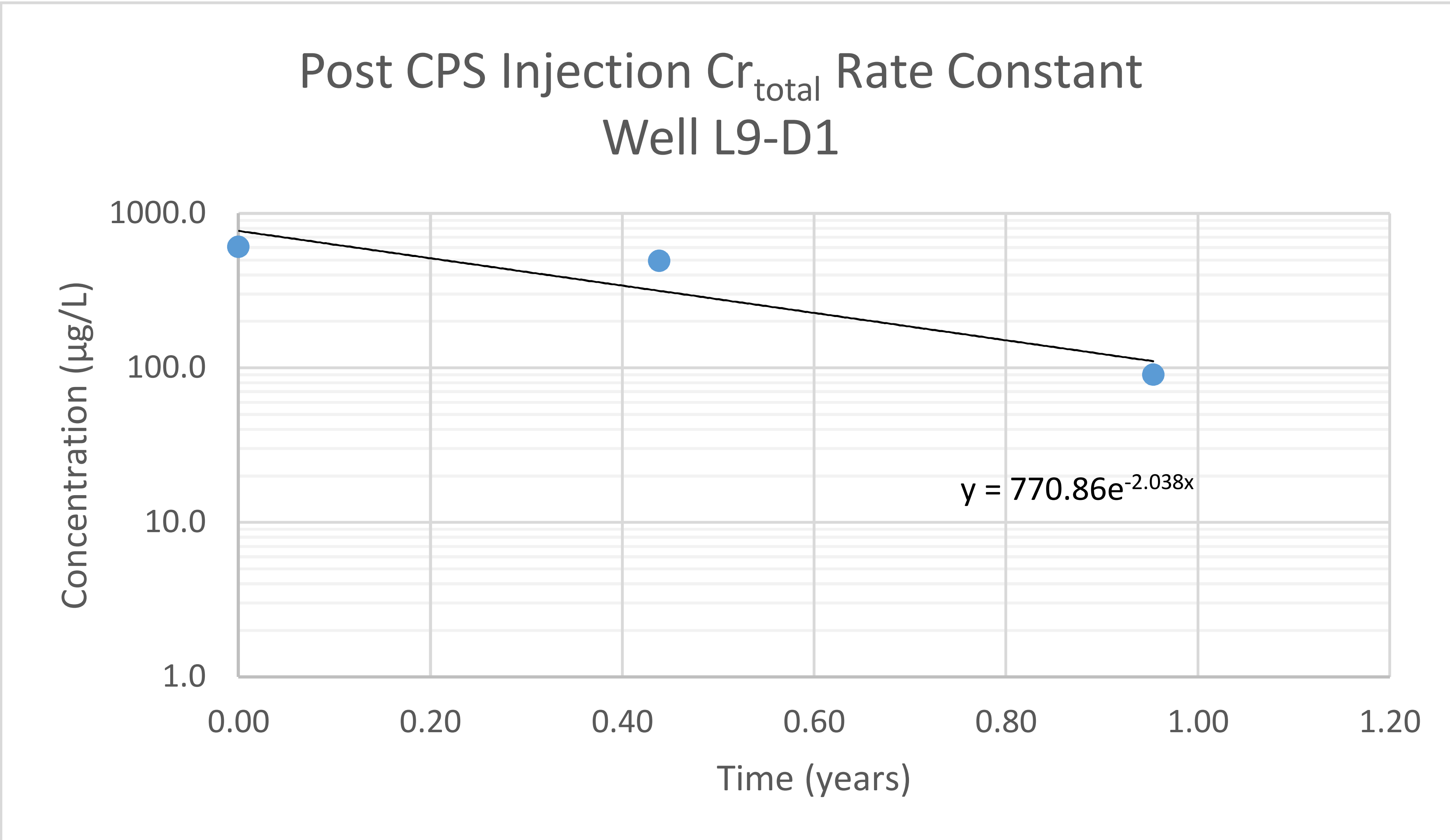
Post CPS Injection Cr total Rate Constant
Well L6-B2
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Time (years)
y = 1333.4e-1.715x



Post CPS Injection Cr total Rate Constant
Well L7-B1
y = 3982.5e-1.515x
10000.0
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Time (years)


Post CPS Injection Cr$_{total}$ Rate Constant
Well L7-C1
Concentration (µg/L)
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Time (years)
$y = 6680.6e^{-2.449x}$


Post CPS Injection Cr total Rate Constant
Well L9-B1
Concentration (µg/L)
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Time (years)
y = 4171.9e-3.593x


Post CPS Injection Cr$_{total}$ Rate Constant
Well L9-D1
1000.0
100.0
10.0
1.0
Concentration (µg/L)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Time (years)
y = 770.86e$^{-2.038x}$

ATTACHMENT B

BIOSCREEN SIMULATIONS OF CHROMIUM REDUCTION FROM CPS AND MNA

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

Cal Run 4a Input Upper Plume Shield Alloy 12.5% Mass, Oct 2013 Cr Concentration - CPS Rxn

Upper Cr Plume Shield Alloy

Run Name

Data Input Instructions:

115	1. Enter value directly....or
or	2. Calculate by filling in grey
0.02	cells below. (To restore formulas, hit button below).
Variable*	Data used directly in model.
20	Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	521.8	*(ft/yr)*
or		or	
Hydraulic Conductivity	*K*	8.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.0017	*(ft/ft)*
Porosity	*n*	0.3	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	24.5	*(ft)*
Transverse Dispersivity*	*alpha y*	2.4	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		or	
Estimated Plume Length	*Lp*	1000	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	1.0	*(-)*
or		or	
Soil Bulk Density	*rho*	1.7	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	5.7E-5	*(-)*

4. GEOCHEMICAL ATTENUATION

1st Order Bulk Att Factor*	*lambda*	2.0E+0	*(per yr)*
or		or	
Solute Half-Life	*t-half*	0.35	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	1400	*(ft)*
Modeled Area Width*	350	*(ft)*
Simulation Time*	5	*(yr)*

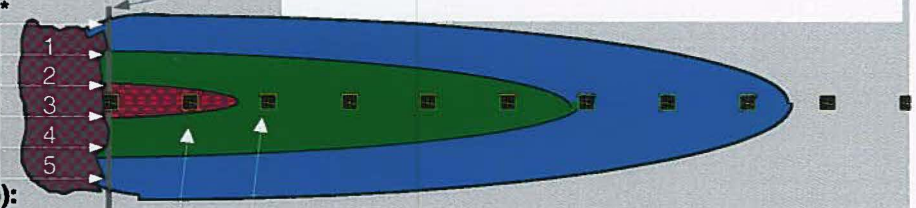
6. SOURCE DATA

Source Thickness in Sat.Zone* 8 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
35	0.05
84	0.55
110	2.5
84	0.55
35	0.05



View of Plume Looking Down

Source Halflife (see Help):

20	20	*(yr)*
Inst. React.	1st Order	
Soluble Mass	438	*(Kg)*
In Source NAPL, Soil		

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	140	280	420	560	700	840	980	1120	1260	1400

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

Recalculate This

Paste Example Dataset

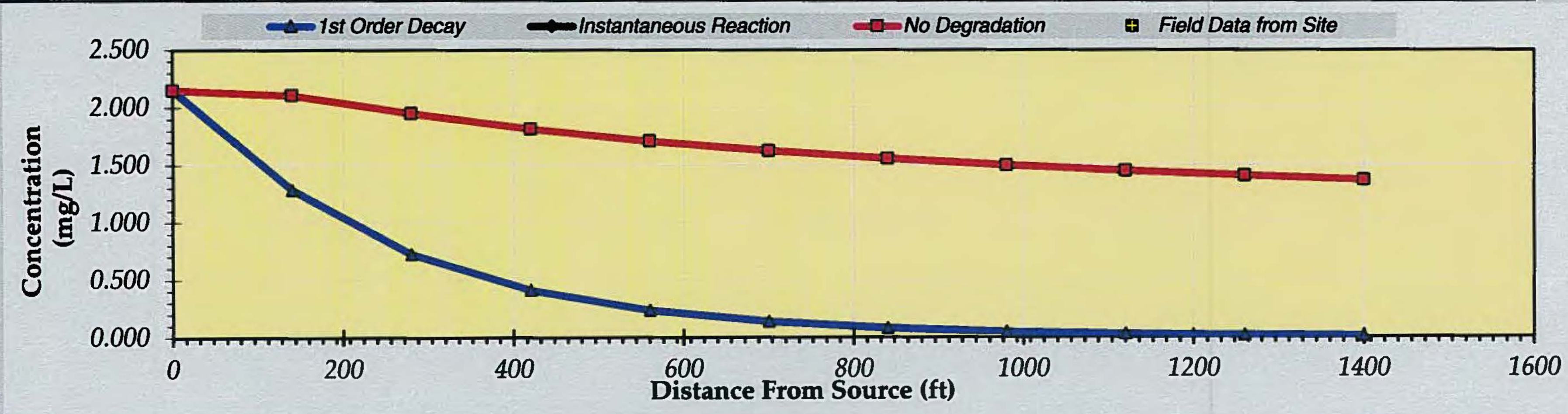
Restore Formulas for Vs,

CAL RUN 4A

UPPER PLUME CHROMIUM CONCENTRATION ALONG PLUME CENTERLINE END OF CPS RXN (mg/L at Z=0)

12.5% Mass

	Distance from Source (ft)										
TYPE OF MODEL	0	140	280	420	560	700	840	980	1120	1260	1400
No Degradation	2.152	2.109	1.952	1.817	1.710	1.626	1.556	1.498	1.448	1.405	1.366
1st Order Decay	2.152	1.286	0.726	0.412	0.236	0.137	0.080	0.047	0.028	0.016	0.010
Inst. Reaction	2.152	2.109	1.952	1.817	1.710	1.626	1.556	1.498	1.448	1.405	1.366
Field Data from Site											



Calculate Animation

Time:
5 Years

Return to

Recalculate This

CAL RUN 4A INPUT, 12.5%M, DISSOLVED CHROMIUM CONCENTRATIONS IN UPPER PLUME AT END OF CPS RXN (mg/L at Z=0)

Transverse Distance (ft)	***Distance from Source (ft)***										
	0	140	280	420	560	700	840	980	1120	1260	1400
175	0.000	0.035	0.035	0.028	0.021	0.015	0.011	0.007	0.005	0.003	0.002
88	0.473	0.395	0.286	0.189	0.121	0.076	0.047	0.029	0.018	0.011	0.007
0	2.152	1.286	0.726	0.412	0.236	0.137	0.080	0.047	0.028	0.016	0.010
-88	0.473	0.395	0.286	0.189	0.121	0.076	0.047	0.029	0.018	0.011	0.007
-175	0.000	0.035	0.035	0.028	0.021	0.015	0.011	0.007	0.005	0.003	0.002
MASS FLUX (mg/day)	3.6E+4	1.8E+4	1.2E+4	7.2E+3	4.4E+3	2.7E+3	1.7E+3	1.0E+3	6.2E+2	3.8E+2	2.3E+2

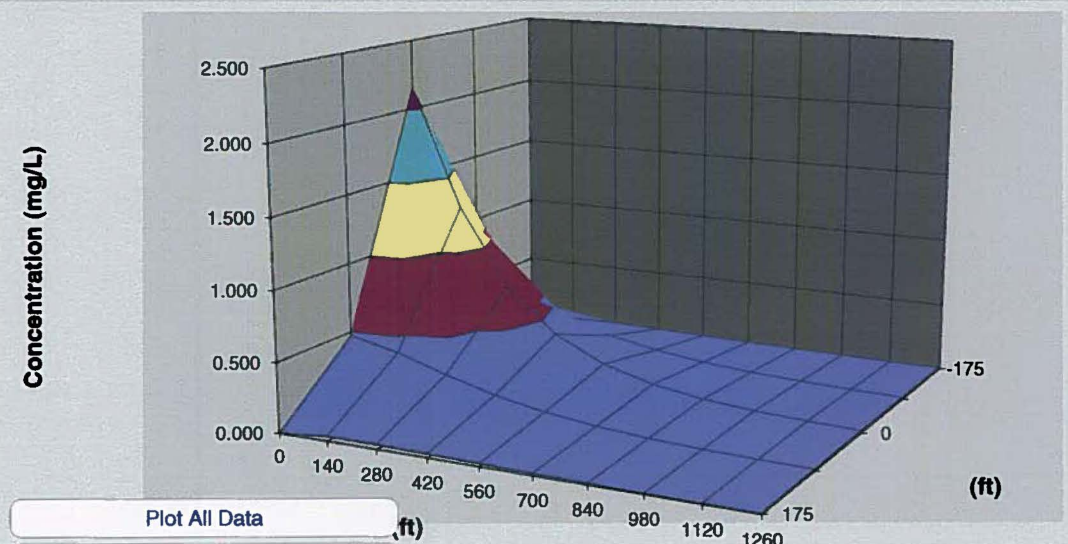
Model to Display:

No Degradation

1st Order Decay

Instantaneous

Time: **5 Years** Target Level: **0.070** mg/L Displayed Model: **1st Order Decay**



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	61.0	*(Kg)*
- Actual Plume Mass	11.1	*(Kg)*
= Plume Mass Removed by Biodeg	**49.9**	*(Kg)* (82 %)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	438.0	*(Kg)*
Contam. Mass in Source Now (t=5Years)	377.0	*(Kg)*
Current Volume of Groundwater in Plume	31.7	*(ac-ft)*
Flowrate of Water Through Source Zone	10.005	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

Cal Run 4a Input Upper Plume Shield Alloy 12.5% Mass, POST CPS Cr CONC - MNA rtf

Upper Cr Plume Shield Alloy

Run Name

Data Input Instructions:

115	*1. Enter value directly....or*
or	*2. Calculate by filling in grey*
0.02	*cells below. (To restore formulas, hit button below).*
Variable*	*Data used directly in model.*
20	*Value calculated by model. (Don't enter any data).*

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	521.8	*(ft/yr)*
or		*or*	
Hydraulic Conductivity	*K*	8.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.0017	*(ft/ft)*
Porosity	*n*	0.3	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	24.5	*(ft)*
Transverse Dispersivity*	*alpha y*	2.4	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		*or*	
Estimated Plume Length	*Lp*	1000	*(ft)*

3. ADSORPTION

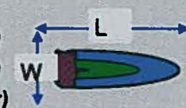
Retardation Factor*	*R*	1.0	*(-)*
or		*or*	
Soil Bulk Density	*rho*	1.7	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	5.7E-5	*(-)*

4. GEOCHEMICAL ATTENUATION

1st Order Bulk Att Factor*	*lambda*	1.8E+0	*(per yr)*
or		*or*	
Solute Half-Life	*t-half*	0.38	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	1400	*(ft)*
Modeled Area Width*	350	*(ft)*
Simulation Time*	117	*(yr)*



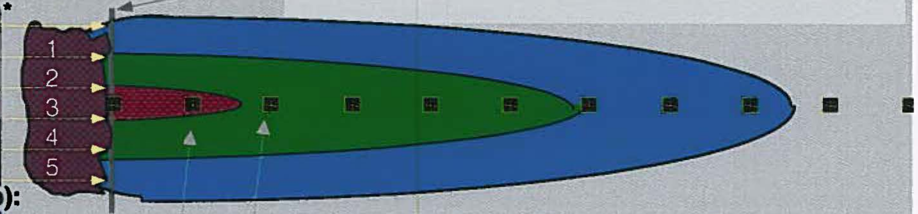
6. SOURCE DATA

Source Thickness in Sat.Zone* 8 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
35	0.095
84	0.422
110	2.125
84	0.422
35	0.095



View of Plume Looking Down

Source Halflife (see Help):

20	20	*(yr)*
Inst. React.	1st Order	
Soluble Mass	377	*(Kg)*

In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	140	280	420	560	700	840	980	1120	1260	1400

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | View Output

RUN ARRAY | View Output

Help | Recalculate This

Paste Example Dataset

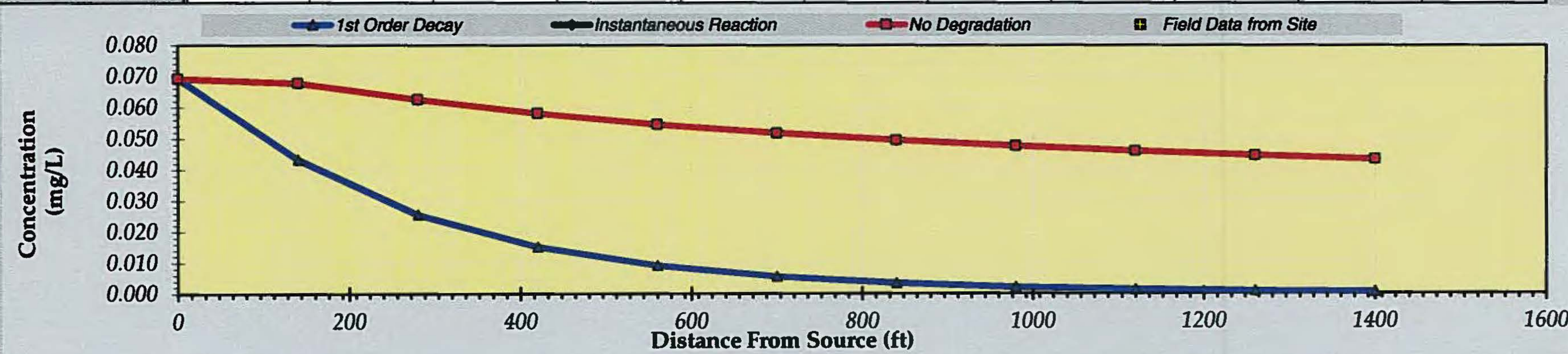
Restore Formulas for Vs,

CAL RUN 4A

UPPER PLUME PREDICTED CHROMIUM CONCENTRATION ALONG PLUME CENTERLINE POST CPS RXN - MNA RTF (mg/L at Z=0)

12.5% Mass

	Distance from Source (ft)										
TYPE OF MODEL	0	140	280	420	560	700	840	980	1120	1260	1400
No Degradation	0.069	0.068	0.063	0.058	0.055	0.052	0.049	0.048	0.046	0.045	0.043
1st Order Decay	0.069	0.043	0.026	0.015	0.009	0.006	0.003	0.002	0.001	0.001	0.000
Inst. Reaction	0.069	0.068	0.063	0.058	0.055	0.052	0.049	0.048	0.046	0.045	0.043
Field Data from Site											



Calculate Animation

Time: 117 Years

Return to

Recalculate This Sheet

Transverse Distance (ft)

CAL RUN 4A INPUT, 12.5%M,DISSOLVED CHROMIUM CONCENTRATIONS IN UPPER PLUME POST CPS RXN - MNA RTF (mg/L at Z=0)

Distance from Source (ft)

	0	140	280	420	560	700	840	980	1120	1260	1400
175	0.000	0.002	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000
88	0.014	0.013	0.010	0.007	0.005	0.003	0.002	0.001	0.001	0.001	0.000
0	0.069	0.043	0.026	0.015	0.009	0.006	0.003	0.002	0.001	0.001	0.000
-88	0.014	0.013	0.010	0.007	0.005	0.003	0.002	0.001	0.001	0.001	0.000
-175	0.000	0.002	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	3.0E+4	6.1E+2	4.1E+2	2.6E+2	1.7E+2	1.1E+2	7.0E+1	4.5E+1	2.9E+1	1.8E+1	1.2E+1

Time: **117 Years**

Target Level: **0.070** mg/L

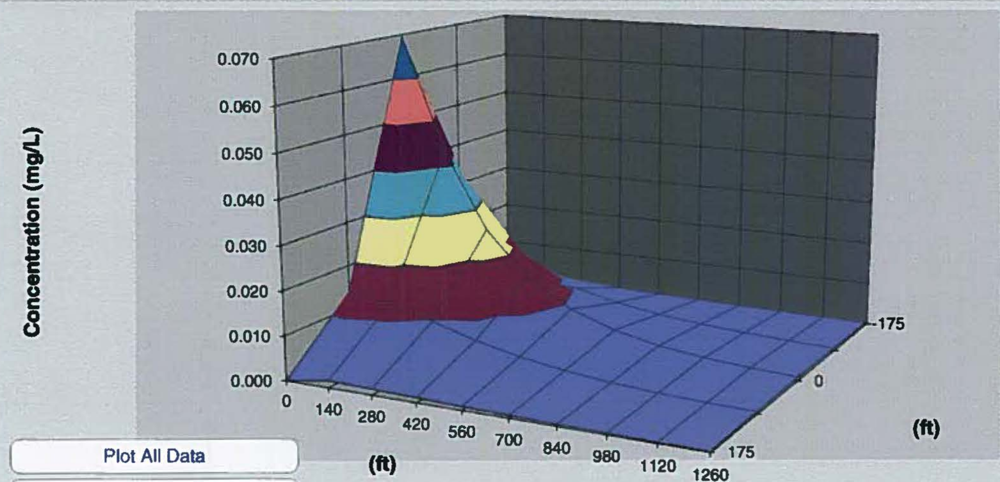
Displayed Model: **1st Order Decay**

Model to Display:

No Degradation Model

1st Order Decay Model

Instantaneous Reaction



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	Can't Calc.	*(Kg)*
- Actual Plume Mass	Can't Calc.	*(Kg)*
= Plume Mass Removed by Biodeg	-	*(Kg)*

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	377.0	*(Kg)*
Contam. Mass in Source Now (t=117Years)	12.3	*(Kg)*
Current Volume of Groundwater in Plume	Can't Calc.	*(ac-ft)*
Flowrate of Water Through Source Zone	Can't Calc.	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

Calibration Run 4a r1 Upper Plume Shield Alloy, 12.5% Mass, Oct 2013 Cr Concentration - CPS RXN

Upper Cr Plume Shield Alloy

Run Name

Data Input Instructions:

115 — 1. Enter value directly....or

or — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

0.02

Variable* — Data used directly in model.

20 — Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	782.7	(ft/yr)
or		or	
Hydraulic Conductivity	K	8.9E-02	(cm/sec)
Hydraulic Gradient	i	0.0017	(ft/ft)
Porosity	n	0.2	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	24.5	(ft)
Transverse Dispersivity*	alpha y	2.4	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or		or	
Estimated Plume Length	Lp	1000	(ft)

3. ADSORPTION

Retardation Factor*	R	1.0	(-)
or		or	
Soil Bulk Density	rho	1.7	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	5.7E-5	(-)

4. GEOCHEMICAL ATTENUATION

1st Order Bulk Att factor*	lambda	2.0E+0	(per yr)
or		or	
Solute Half-Life	t-half	0.35	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	0	(mg/L)
Delta Nitrate*	NO3	0	(mg/L)
Observed Ferrous Iron*	Fe2+	0	(mg/L)
Delta Sulfate*	SO4	0	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	2200	(ft)
Modeled Area Width*	350	(ft)
Simulation Time*	5	(yr)

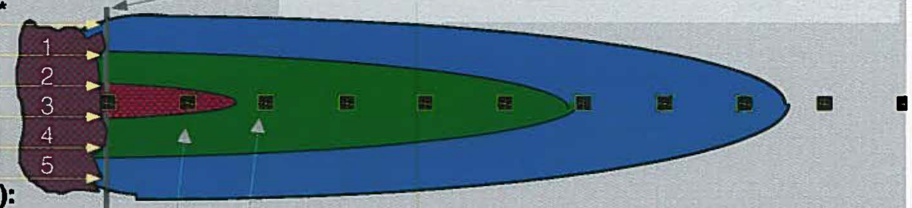
6. SOURCE DATA

Source Thickness in Sat.Zone* 7 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
35	0.05
84	0.55
110	2.5
84	0.55
35	0.05



View of Plume Looking Down

Source Halflife (see Help):

30	30	(yr)
Inst. React.	1st Order	
Soluble Mass	438	(Kg)

In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	220	440	660	880	1100	1320	1540	1760	1980	2200

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — View Output

RUN ARRAY — View Output

Help

Recalculate This

Paste Example Dataset

Restore Formulas for Vs,

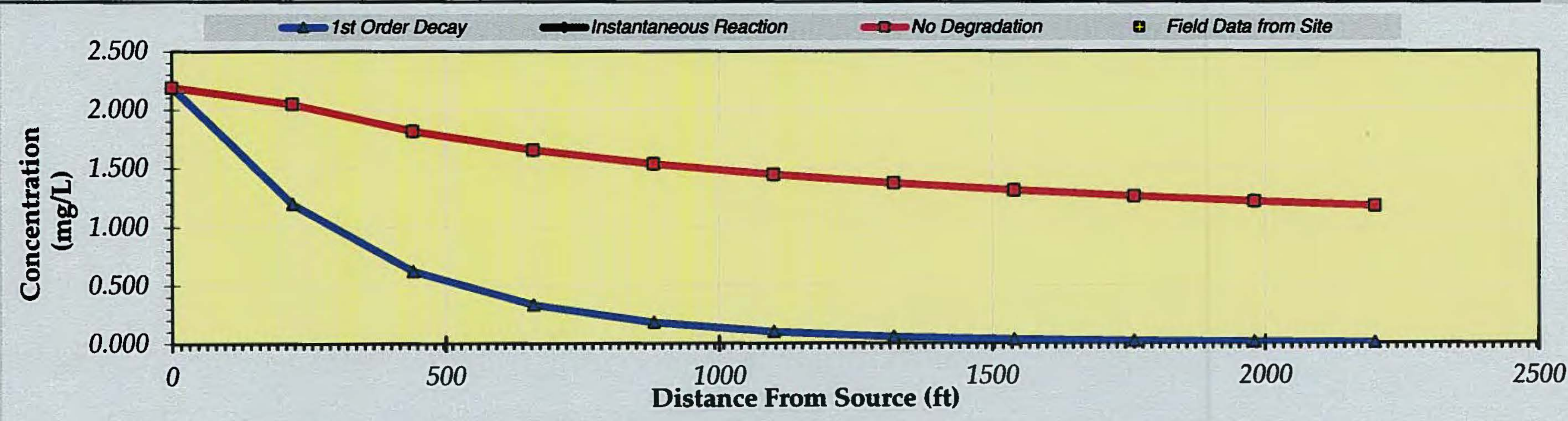
CAL RUN 4A r1

UPPER PLUME CHROMIUM CONCENTRATION ALONG CENTERLINE AT END OF CPS RXN (mg/L at Z=0)

12.5 % Mass

Distance from Source (ft)

TYPE OF MODEL	0	220	440	660	880	1100	1320	1540	1760	1980	2200
No Degradation	2.192	2.047	1.815	1.653	1.535	1.444	1.370	1.309	1.258	1.213	1.175
1st Order Decay	2.192	1.199	0.622	0.332	0.181	0.100	0.055	0.031	0.017	0.010	0.006
Inst. Reaction	2.192	2.047	1.815	1.653	1.535	1.444	1.370	1.309	1.258	1.213	1.175
Field Data from Site											



Calculate Animation

Time: 5 Years

Return to

Recalculate This

CAL RUN 4A R1 INPUT, 12.5%m, DISSOLVED CHROMIUM CONCENTRATIONS IN UPPER PLUME AT END OF CPS RXN (mg/L at Z=0)

Transverse Distance (ft) ↓	***Distance from Source (ft)***										
	0	220	440	660	880	1100	1320	1540	1760	1980	2200
175	0.000	0.048	0.044	0.034	0.025	0.017	0.012	0.008	0.005	0.003	0.002
88	0.482	0.432	0.291	0.180	0.108	0.064	0.037	0.022	0.013	0.007	0.004
0	2.192	1.199	0.622	0.332	0.181	0.100	0.055	0.031	0.017	0.010	0.006
-88	0.482	0.432	0.291	0.180	0.108	0.064	0.037	0.022	0.013	0.007	0.004
-175	0.000	0.048	0.044	0.034	0.025	0.017	0.012	0.008	0.005	0.003	0.002
MASS FLUX (mg/day)	3.2E+4	1.6E+4	9.6E+3	5.7E+3	3.3E+3	1.9E+3	1.1E+3	6.7E+2	3.9E+2	2.3E+2	1.3E+2

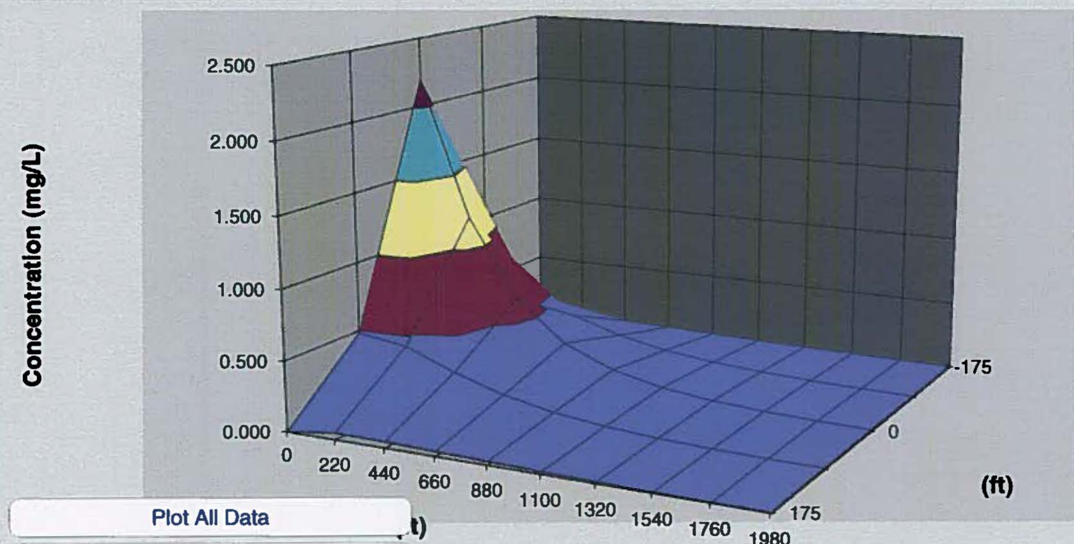
Model to Display:

No Degradation

1st Order Decay

Instantaneous

Time: **5 Years** Target Level: **0.070** mg/L Displayed Model: **1st Order Decay**



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	53.9	*(Kg)*
- Actual Plume Mass	9.2	*(Kg)*
= Plume Mass Removed by Biodeg	**44.7**	*(Kg)* (83 %)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	438.0	*(Kg)*
Contam. Mass in Source Now (t=5Years)	384.1	*(Kg)*
Current Volume of Groundwater in Plume	27.8	*(ac-ft)*
Flowrate of Water Through Source Zone	8.754	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

Calibration Run 4a r1 Upper Plume Shield Alloy, 12.5% Mass, POST CPS Cr CONC - MNA rtf

Upper Cr Plume Shield Alloy
Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
or 0.02 → 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* → Data used directly in model.
20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	782.7	*(ft/yr)*
or		*or*	
Hydraulic Conductivity	*K*	8.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.0017	*(ft/ft)*
Porosity	*n*	0.2	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	24.5	*(ft)*
Transverse Dispersivity*	*alpha y*	2.4	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		*or*	
Estimated Plume Length	*Lp*	1000	*(ft)*

3. ADSORPTION

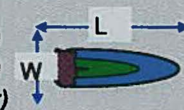
Retardation Factor*	*R*	1.0	*(-)*
or		*or*	
Soil Bulk Density	*rho*	1.7	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	5.7E-5	*(-)*

4. GEOCHEMICAL ATTENUATION

1st Order Bulk Att factor*	*lambda*	1.8E+0	*(per yr)*
or		*or*	
Solute Half-Life	*t-half*	0.38	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	2200	*(ft)*
Modeled Area Width*	350	*(ft)*
Simulation Time*	133	*(yr)*



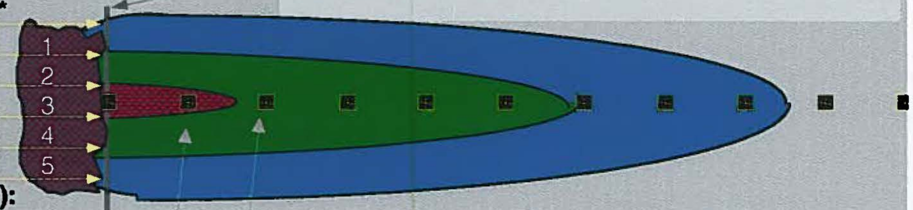
6. SOURCE DATA

Source Thickness in Sat.Zone* 7 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
35	0.0984
84	0.438
110	2.192
84	0.438
35	0.0984



View of Plume Looking Down

Source Halflife (see Help):

Inst. React.	1st Order	
30	30	*(yr)*

Soluble Mass 384 *(Kg)*
In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	220	440	660	880	1100	1320	1540	1760	1980	2200

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — View Output

RUN ARRAY — View Output

Help — Recalculate This

Paste Example Dataset

Restore Formulas for Vs,

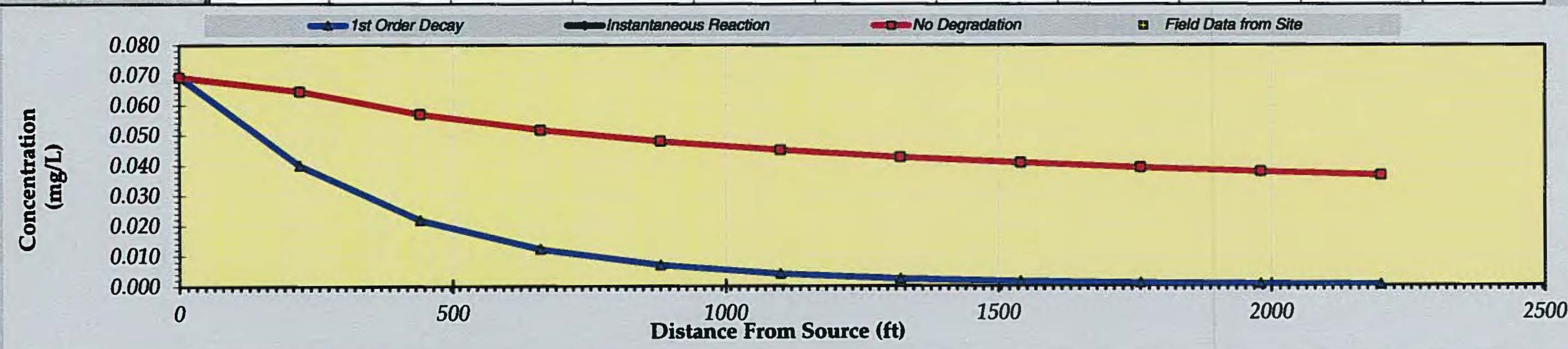
CAL RUN 4A r1

UPPER PLUME PREDICTED CHROMIUM CONCENTRATION ALONG CENTERLINE POST CPS RXN - MNA RTF (mg/L at Z=0)

12.5 % Mass

Distance from Source (ft)

TYPE OF MODEL	0	220	440	660	880	1100	1320	1540	1760	1980	2200
No Degradation	0.069	0.065	0.057	0.052	0.048	0.045	0.043	0.041	0.039	0.038	0.037
1st Order Decay	0.069	0.040	0.022	0.012	0.007	0.004	0.002	0.001	0.001	0.001	0.000
Inst. Reaction	0.069	0.065	0.057	0.052	0.048	0.045	0.043	0.041	0.039	0.038	0.037
Field Data from Site											



Calculate Animation

Time:

133 Years

Return to

Recalculate This Sheet

Transverse Distance (ft) CAL RUN 4A R1 INPUT, 12.5%m, DISSOLVED CHROMIUM CONCENTRATIONS IN UPPER PLUME POST CPS RXN - MNA RTF (mg/L at Z=0)

Distance from Source (ft)

	0	220	440	660	880	1100	1320	1540	1760	1980	2200
175	0.000	0.002	0.002	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000
88	0.014	0.014	0.010	0.007	0.004	0.003	0.002	0.001	0.001	0.000	0.000
0	0.069	0.040	0.022	0.012	0.007	0.004	0.002	0.001	0.001	0.001	0.000
-88	0.014	0.014	0.010	0.007	0.004	0.003	0.002	0.001	0.001	0.000	0.000
-175	0.000	0.002	0.002	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	2.7E+4	5.3E+2	3.3E+2	2.1E+2	1.3E+2	8.0E+1	4.9E+1	3.0E+1	1.9E+1	1.2E+1	7.2E+0

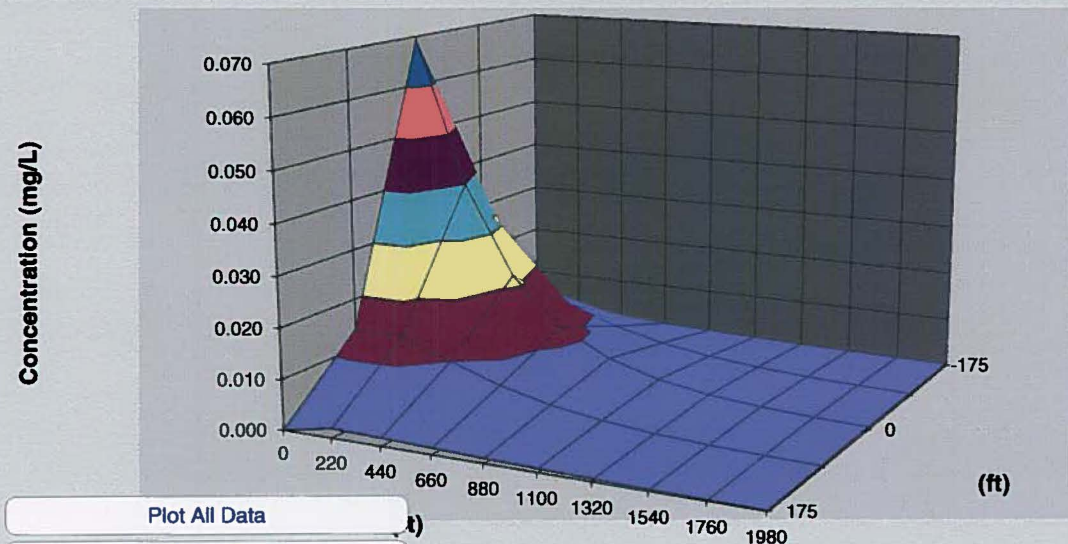
Time: **133 Years** Target Level: **0.070** mg/L Displayed Model: **1st Order Decay**

Model to Display:

No Degradation

1st Order Decay

Instantaneous



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	Can't Calc.	*(Kg)*
- Actual Plume Mass	Can't Calc.	*(Kg)*
= Plume Mass Removed by Biodeg	-	*(Kg)*

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	384.0	*(Kg)*
Contam. Mass in Source Now (t=133Years)	12.1	*(Kg)*
Current Volume of Groundwater in Plume	Can't Calc.	*(ac-ft)*
Flowrate of Water Through Source Zone	Can't Calc.	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

Calibration Run 5a r1 Input Upper Plume Shield Alloy 12.5% Mass, Oct 2013 Cr Concentration - CPS Rxn

Upper Cr Plume Shield Alloy

Run Name

Data Input Instructions:

115	1. Enter value directly....or
or	2. Calculate by filling in grey
0.02	cells below. (To restore formulas, hit button below).
Variable*	Data used directly in model.
20	Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	452.3	*(ft/yr)*
or		or	
Hydraulic Conductivity	*K*	9.0E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.0017	*(ft/ft)*
Porosity	*n*	0.35	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	28.9	*(ft)*
Transverse Dispersivity*	*alpha y*	2.9	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		or	
Estimated Plume Length	*Lp*	1500	*(ft)*

3. ADSORPTION

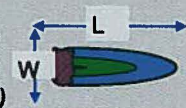
Retardation Factor*	*R*	1.0	*(-)*
or		or	
Soil Bulk Density	*rho*	1.7	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	5.7E-5	*(-)*

4. GEOCHEMICAL ATTENUATION

1st Order Bulk Att Factor*	*lambda*	2.0E+0	*(per yr)*
or		or	
Solute Half-Life	*t-half*	0.35	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	2000	*(ft)*
Modeled Area Width*	350	*(ft)*
Simulation Time*	5	*(yr)*



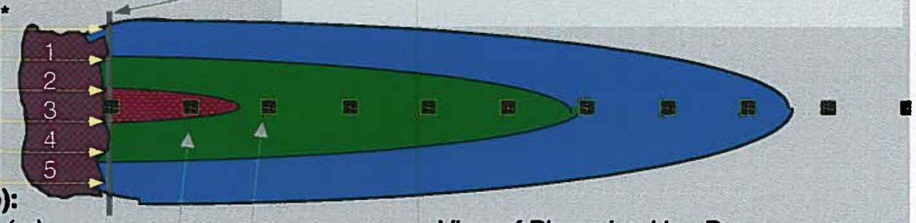
6. SOURCE DATA

Source Thickness in Sat.Zone* 9 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Zone	Width* (ft)	Conc. (mg/L)*
1	35	0.05
2	84	0.55
3	110	2.5
4	84	0.55
5	35	0.05



Source Halflife (see Help):

20	20	*(yr)*
Inst. React.	1st Order	
Soluble Mass	475	*(Kg)*

In Source NAPL, Soil

View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	200	400	600	800	1000	1200	1400	1600	1800	2000

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | **View Output**

RUN ARRAY | **View Output**

Help | Recalculate This

Paste Example Dataset

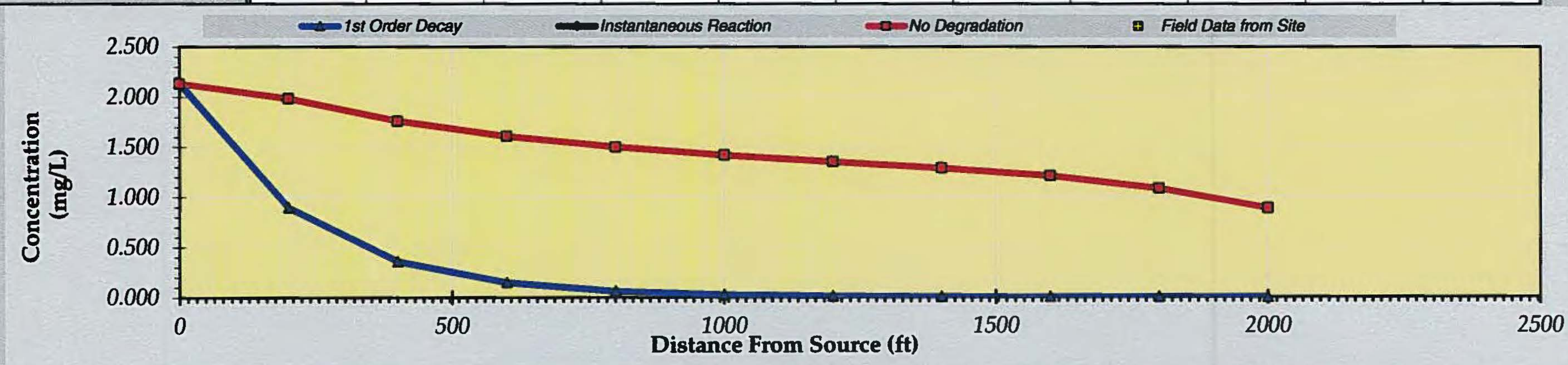
Restore Formulas for Vs,

CAL RUN 5AR1, 0.75 ppm Cr

UPPER PLUME CHROMIUM CONCENTRATION ALONG PLUME CENTERLINE AT END OF CPS RXN (mg/L at Z=0)

12.5% Mass

	Distance from Source (ft)										
TYPE OF MODEL	0	200	400	600	800	1000	1200	1400	1600	1800	2000
No Degradation	2.136	1.988	1.762	1.611	1.503	1.420	1.353	1.290	1.211	1.085	0.887
1st Order Decay	2.136	0.899	0.360	0.149	0.063	0.027	0.012	0.005	0.002	0.001	0.000
Inst. Reaction	2.136	1.988	1.762	1.611	1.503	1.420	1.353	1.290	1.211	1.085	0.887
Field Data from Site											



Calculate Animation

Time: 5 Years

Return to

Recalculate This Sheet

CAL RUN 5A R1 12.5%M, DISSOLVED CHROMIUM CONCENTRATIONS IN UPPER PLUME AT END OF CPS RXN (mg/L at Z=0)

Transverse Distance (ft) ↓ \ Distance from Source (ft)	0	200	400	600	800	1000	1200	1400	1600	1800	2000
175	0.000	0.038	0.027	0.016	0.009	0.005	0.003	0.001	0.001	0.000	0.000
88	0.470	0.332	0.173	0.083	0.038	0.018	0.008	0.004	0.002	0.001	0.000
0	2.136	0.899	0.360	0.149	0.063	0.027	0.012	0.005	0.002	0.001	0.000
-88	0.470	0.332	0.173	0.083	0.038	0.018	0.008	0.004	0.002	0.001	0.000
-175	0.000	0.038	0.027	0.016	0.009	0.005	0.003	0.001	0.001	0.000	0.000
MASS FLUX (mg/day)	4.1E+4	1.6E+4	7.3E+3	3.4E+3	1.5E+3	7.0E+2	3.2E+2	1.4E+2	6.5E+1	2.9E+1	1.3E+1

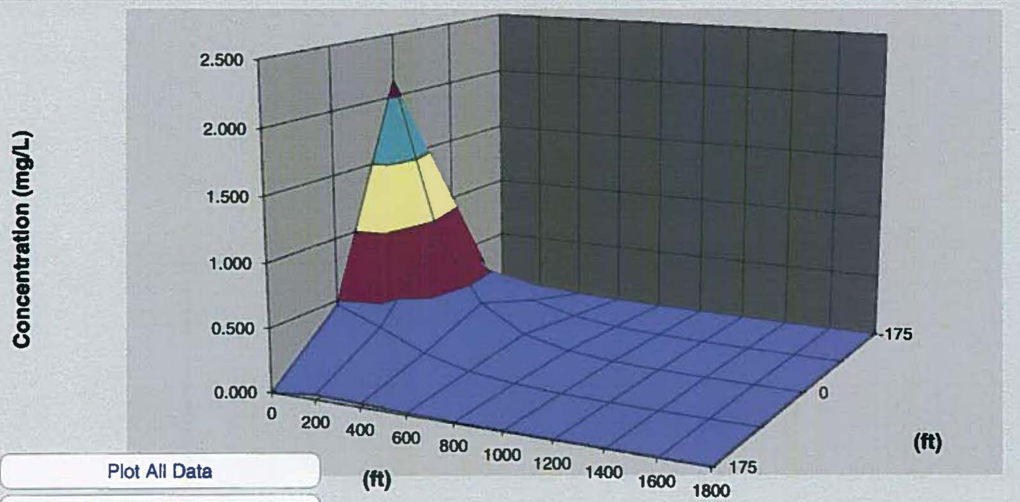
Time: **5 Years**   Target Level: **0.070** mg/L   Displayed Model: **1st Order Decay**

Model to Display:

No Degradation Model

1st Order Decay Model

Instantaneous Reaction



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	69.2	*(Kg)*
- Actual Plume Mass	8.3	*(Kg)*
= Plume Mass Removed by Biodeg	**60.9**	*(Kg)* (88 %)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	475.0	*(Kg)*
Contam. Mass in Source Now (t=5Years)	405.8	*(Kg)*
Current Volume of Groundwater in Plume	40.5	*(ac-ft)*
Flowrate of Water Through Source Zone	11.382	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

Calibration Run 5a r1 Input Upper Plume Shield Alloy 12.5% Mass, Post CPS Cr Conc - MNA rtf

Upper Cr Plume Shield Alloy

Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
or → 2. Calculate by filling in grey
0.02 — cells below. (To restore formulas, hit button below).

Variable* → Data used directly in model.

20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	452.3	*(ft/yr)*
or		or	
Hydraulic Conductivity	*K*	9.0E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.0017	*(ft/ft)*
Porosity	*n*	0.35	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	28.9	*(ft)*
Transverse Dispersivity*	*alpha y*	2.9	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		or	
Estimated Plume Length	*Lp*	1500	*(ft)*

3. ADSORPTION

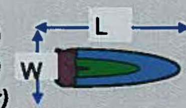
Retardation Factor*	*R*	1.0	*(-)*
or		or	
Soil Bulk Density	*rho*	1.7	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	5.7E-5	*(-)*

4. GEOCHEMICAL ATTENUATION

1st Order Bulk Att Factor*	*lambda*	1.7E+0	*(per yr)*
or		or	
Solute Half-Life	*t-half*	0.40	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	2000	*(ft)*
Modeled Area Width*	350	*(ft)*
Simulation Time*	111	*(yr)*



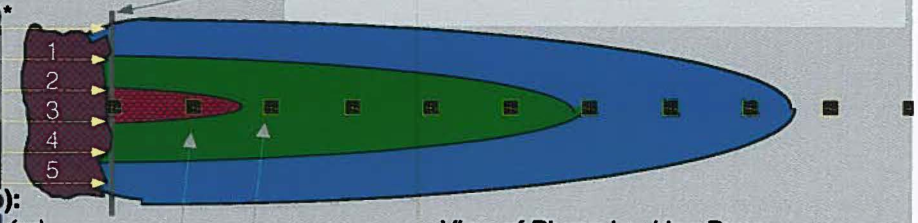
6. SOURCE DATA

Source Thickness in Sat.Zone* 9 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
35	0.094
84	0.419
110	2.136
84	0.419
35	0.094



View of Plume Looking Down

Source Halflife (see Help):

Inst. React.	1st Order	
20	20	*(yr)*

Soluble Mass 406 *(Kg)*

In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	200	400	600	800	1000	1200	1400	1600	1800	2000

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

Recalculate This

Paste Example Dataset

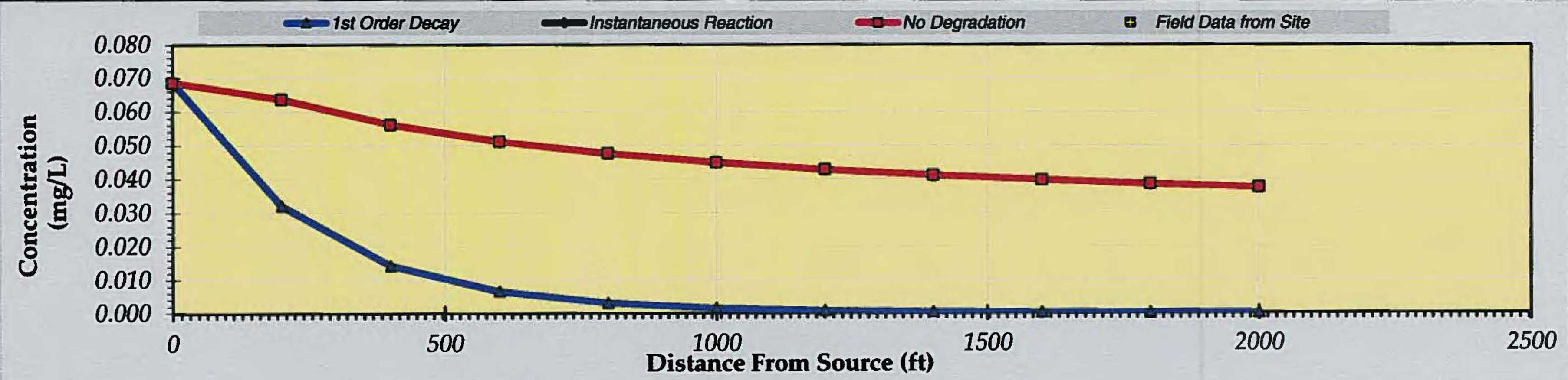
Restore Formulas for Vs,

CAL RUN 5AR1

PPER PLUME CHROMIUM CONCENTRATION ALONG PLUME CENTERLINE POST CPS RXN - MNA rtf (mg/L at Z=0)

12.5% Mass

	Distance from Source (ft)										
TYPE OF MODEL	0	200	400	600	800	1000	1200	1400	1600	1800	2000
No Degradation	0.069	0.064	0.056	0.051	0.048	0.045	0.043	0.041	0.040	0.038	0.037
1st Order Decay	0.069	0.032	0.014	0.007	0.003	0.001	0.001	0.000	0.000	0.000	0.000
Inst. Reaction	0.069	0.064	0.056	0.051	0.048	0.045	0.043	0.041	0.040	0.038	0.037
Field Data from Site											



Calculate Animation

Time:

111 Years

Return to

Recalculate This

CAL RUN 5A R1 12.5%m, DISSOLVED CHROMIUM CONCENTRATIONS IN UPPER PLUME POST CPS RXN - MNA RTF (mg/L at Z=0)

Transverse Distance (ft) ↓	*Distance from Source (ft)* 0	200	400	600	800	1000	1200	1400	1600	1800	2000
175	0.000	0.002	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
88	0.013	0.011	0.007	0.004	0.002	0.001	0.000	0.000	0.000	0.000	0.000
0	0.069	0.032	0.014	0.007	0.003	0.001	0.001	0.000	0.000	0.000	0.000
-88	0.013	0.011	0.007	0.004	0.002	0.001	0.000	0.000	0.000	0.000	0.000
-175	0.000	0.002	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	3.4E+4	5.6E+2	2.9E+2	1.5E+2	7.5E+1	3.8E+1	1.9E+1	9.8E+0	4.9E+0	2.5E+0	1.3E+0

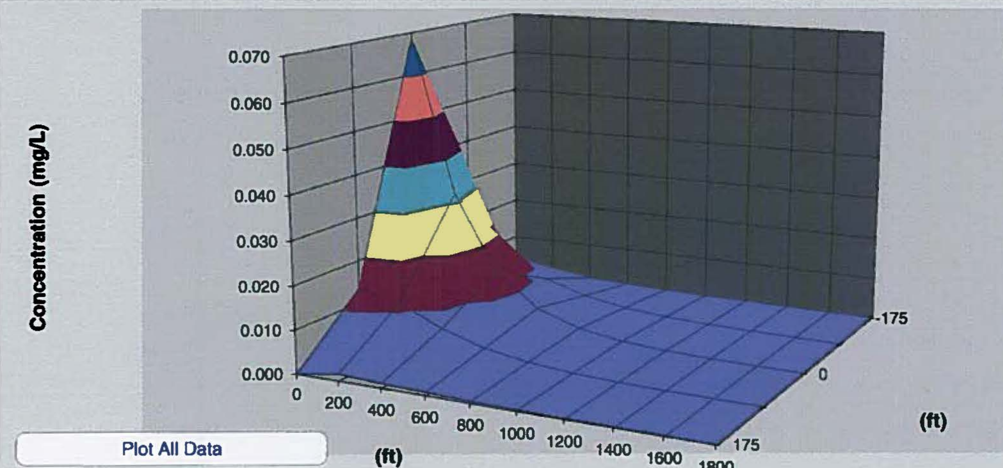
Time: **111 Years** Target Level: **0.070** mg/L Displayed Model: **1st Order Decay**

Model to Display:

No Degradation Model

1st Order Decay Model

Instantaneous Reaction



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	Can't Calc.	*(Kg)*
- Actual Plume Mass	Can't Calc.	*(Kg)*
= Plume Mass Removed by Biodeg	-	*(Kg)*

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	406.0	*(Kg)*
Contam. Mass in Source Now (t=111Years)	13.0	*(Kg)*
Current Volume of Groundwater in Plume	Can't Calc.	*(ac-ft)*
Flowrate of Water Through Source Zone	Can't Calc.	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

Run 5 Cal parameters for Lower Aquifer, Predicted Chromium Concentrations at End of CPS Reactivity

Run Name
Lower Cr Plume
Shield Alloy

Data Input Instructions:

115	1. Enter value directly....or
or	2. Calculate by filling in grey
0.02	cells below. (To restore formulas, hit button below).
Variable*	Data used directly in model.
20	Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	298.0	*(ft/yr)*
or		*or*	
Hydraulic Conductivity	*K*	3.6E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.0016	*(ft/ft)*
Porosity	*n*	0.2	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	24.5	*(ft)*
Transverse Dispersivity*	*alpha y*	2.4	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		*or*	
Estimated Plume Length	*Lp*	1000	*(ft)*

3. ADSORPTION

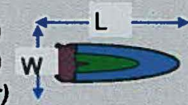
Retardation Factor*	*R*	1.0	*(-)*
or		*or*	
Soil Bulk Density	*rho*	1.7	*(kg/l)*
Partition Coefficient	*Koc*	1000	*(L/kg)*
FractionOrganicCarbon	*foc*	5.7E-6	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	1.1E+0	*(per yr)*
or		*or*	
Solute Half-Life	*t-half*	0.63	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	4000	*(ft)*
Modeled Area Width*	400	*(ft)*
Simulation Time*	25	*(yr)*



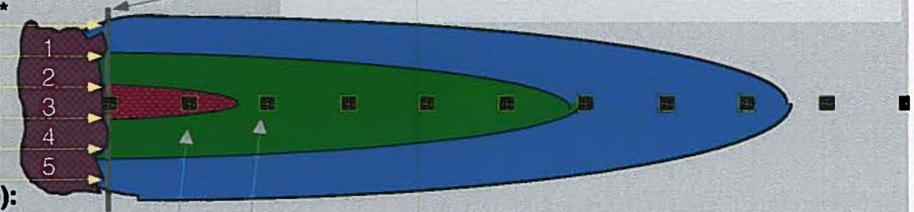
6. SOURCE DATA

Source Thickness in Sat.Zone* 7 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
42	0.05
60	0.3
192	6.986
60	0.3
42	0.05



Source Halflife (see Help):

50	50	*(yr)*
Inst. React.	1st Order	

Soluble Mass 1100 *(Kg)*

In Source Soil porewater

View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	400	800	1200	1600	2000	2400	2800	3200	3600	4000

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE

View Output

RUN ARRAY

View Output

Help

Recalculate This

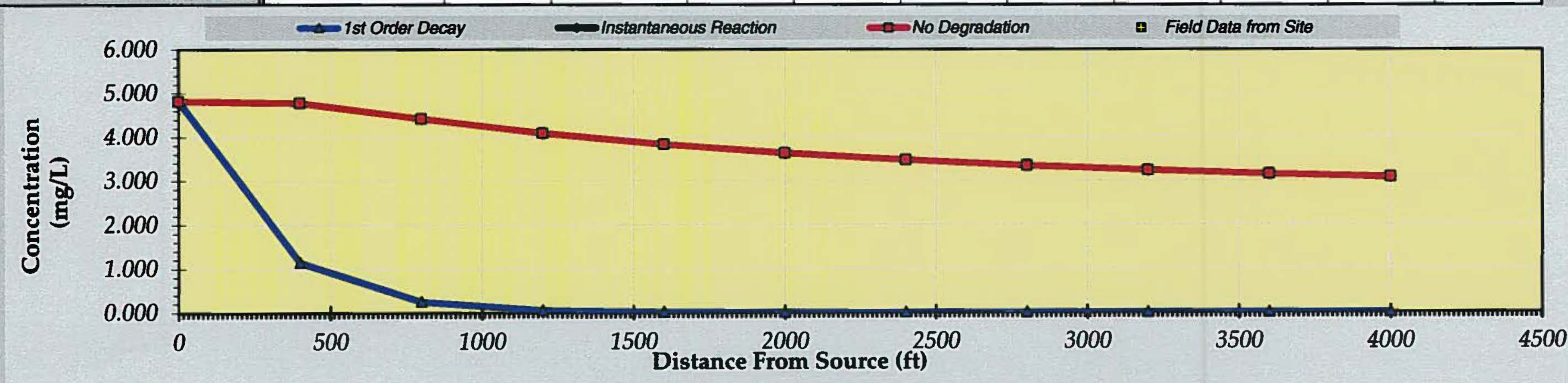
Paste Example Dataset

Restore Formulas for Vs,

CAL RUN 5 INPUT

LOWER PLUME CHROMIUM CONCENTRATION ALONG PLUME CENTERLINE AT END OF CPS RXN (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	400	800	1200	1600	2000	2400	2800	3200	3600	4000
No Degradation	4.822	4.782	4.423	4.092	3.831	3.628	3.467	3.338	3.234	3.147	3.076
1st Order Decay	4.822	1.151	0.256	0.057	0.013	0.003	0.001	0.000	0.000	0.000	0.000
Inst. Reaction	4.822	4.782	4.423	4.092	3.831	3.628	3.467	3.338	3.234	3.147	3.076
Field Data from Site											



Calculate Animation

estep

estep

Time:

25 Years

Return to

Recalculate This

RUN 5 INPUT PREDICTED CHROMIUM CONCENTRATIONS IN LOWERPLUME AT END OF CPS RXN (mg/L at Z=0)

Distance from Source (ft)

Transverse Distance (ft)	0	400	800	1200	1600	2000	2400	2800	3200	3600	4000
200	0.000	0.022	0.017	0.007	0.002	0.001	0.000	0.000	0.000	0.000	0.000
100	0.207	0.573	0.143	0.035	0.008	0.002	0.000	0.000	0.000	0.000	0.000
0	4.822	1.151	0.256	0.057	0.013	0.003	0.001	0.000	0.000	0.000	0.000
-100	0.207	0.573	0.143	0.035	0.008	0.002	0.000	0.000	0.000	0.000	0.000
-200	0.000	0.022	0.017	0.007	0.002	0.001	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	4.5E+4	7.6E+3	1.9E+3	4.6E+2	1.1E+2	2.7E+1	6.6E+0	1.6E+0	3.8E-1	9.3E-2	2.3E-2

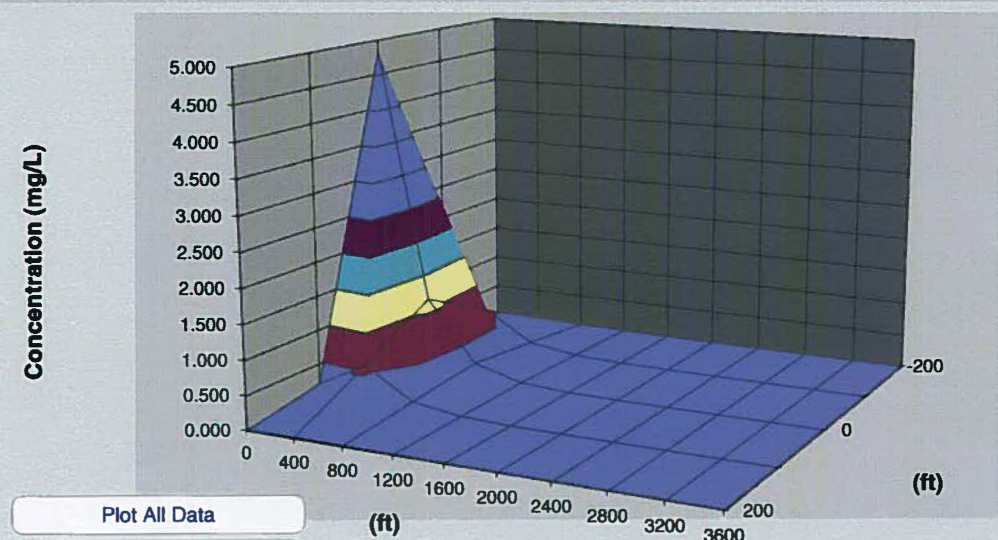
Model to Display:

No Degradation

1st Order Decay

Instantaneous

Time: **25 Years** Target Level: **0.070** mg/L Displayed Model: **1st Order Decay**



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation 340.7 *(Kg)*

- Actual Plume Mass 17.6 *(Kg)*

= Plume Mass Removed by Biodeg **323.1** *(Kg)* (95 %)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years) 1100.0 *(Kg)*

Contam. Mass in Source Now (t=25Years) 759.3 *(Kg)*

Current Volume of Groundwater in Plume 27.0 *(ac-ft)*

Flowrate of Water Through Source Zone 3.792 *(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

Run 5 Cal parameters for Lower Aquifer, Predicted Chromium Concentrations Post CPS - MNA RTF

Lower Cr Plume
Shield Alloy
Run Name

Data Input Instructions:

115	1. *Enter value directly....or*
or	2. *Calculate by filling in grey*
0.02	*cells below. (To restore formulas, hit button below).*
Variable*	*Data used directly in model.*
20	*Value calculated by model. (Don't enter any data).*

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	298.0	*(ft/yr)*
or		or	
Hydraulic Conductivity	*K*	3.6E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.0016	*(ft/ft)*
Porosity	*n*	0.2	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	24.5	*(ft)*
Transverse Dispersivity*	*alpha y*	2.4	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		or	
Estimated Plume Length	*Lp*	1000	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	1.3	*(-)*
or		or	
Soil Bulk Density	*rho*	1.7	*(kg/l)*
Partition Coefficient	*Koc*	1000	*(L/kg)*
FractionOrganicCarbon	*foc*	5.7E-6	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	8.3E-1	*(per yr)*
or		or	
Solute Half-Life	*t-half*	0.83	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	1500	*(ft)*
Modeled Area Width*	400	*(ft)*
Simulation Time*	287	*(yr)*

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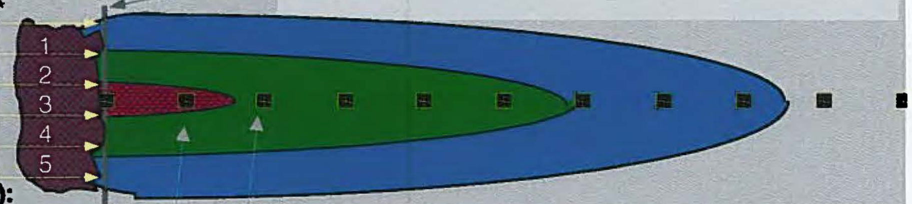
6. SOURCE DATA

Source Thickness in Sat.Zone* 7 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Zone	Width* (ft)	Conc. (mg/L)*
1	42	0.0476
2	60	0.153
3	192	4.822
4	60	0.153
5	42	0.0476



View of Plume Looking Down

Source Halflife (see Help):

Inst. React.	1st Order	
50	50	*(yr)*

Soluble Mass 759 *(Kg)*
In Source Soil porewater

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	150	300	450	600	750	900	1050	1200	1350	1500

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | **View Output**

RUN ARRAY | **View Output**

Help | Recalculate This

Paste Example Dataset

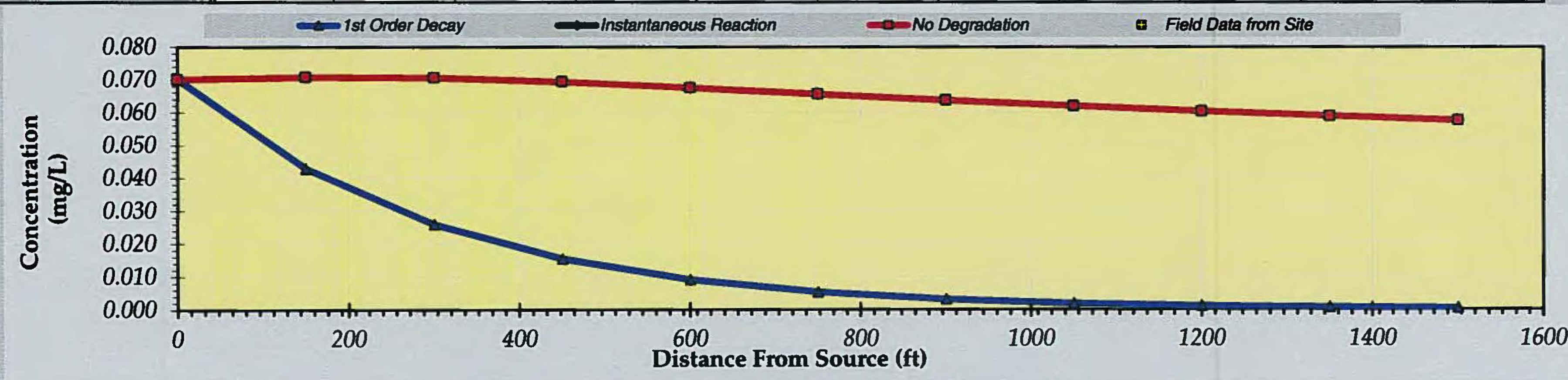
Restore Formulas for Vs,

CAL RUN 5 INPUT

LOWER PLUME CHROMIUM CONCENTRATION ALONG PLUME CENTERLINE AT END OF CPS RXN MNA RTF (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	150	300	450	600	750	900	1050	1200	1350	1500
No Degradation	0.070	0.071	0.071	0.069	0.067	0.065	0.064	0.062	0.060	0.059	0.057
1st Order Decay	0.070	0.043	0.026	0.015	0.009	0.005	0.003	0.002	0.001	0.001	0.000
Inst. Reaction	0.070	0.071	0.071	0.069	0.067	0.065	0.064	0.062	0.060	0.059	0.057
Field Data from Site											



Calculate Animation

step

step

Time:

287 Years

Return to

Recalculate This Sheet

CALRUN 5 INPUT PREDICTED DISSOLVED CHROMIUM CONCENTRATIONS IN PLUME POST CPS RXN- MNA RTF (mg/L at Z=0)

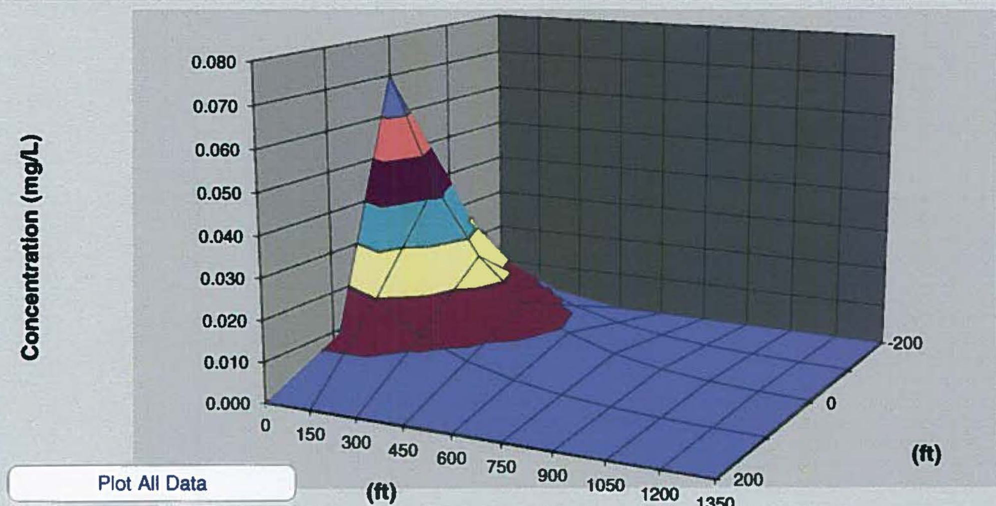
Distance from Source (ft)

Transverse Distance (ft) ↓	0	150	300	450	600	750	900	1050	1200	1350	1500
200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.002	0.020	0.012	0.008	0.005	0.003	0.002	0.001	0.001	0.000	0.000
0	0.070	0.043	0.026	0.015	0.009	0.005	0.003	0.002	0.001	0.001	0.000
-100	0.002	0.020	0.012	0.008	0.005	0.003	0.002	0.001	0.001	0.000	0.000
-200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	3.1E+4	2.7E+2	1.7E+2	1.0E+2	6.2E+1	3.8E+1	2.3E+1	1.4E+1	8.6E+0	5.3E+0	3.2E+0

Time: **287 Years**   Target Level: **0.070** mg/L   Displayed Model: **1st Order Decay**

Model to Display:

- *No Degradation*
- *1st Order Decay*
- *Instantaneous*



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	Can't Calc.	*(Kg)*
- Actual Plume Mass	Can't Calc.	*(Kg)*
= Plume Mass Removed by Biodeg	-	*(Kg)*

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	759.3	*(Kg)*
Contam. Mass in Source Now (t=287Years)	11.0	*(Kg)*
Current Volume of Groundwater in Plume	Can't Calc.	*(ac-ft)*
Flowrate of Water Through Source Zone	Can't Calc.	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

Run 6 Cal Input Parameters for Lower Aquifer, Predicted Chromium Concentrations at End of CPS Reactivity

Lower Cr Plume
Shield Alloy
Run Name

Data Input Instructions:

115	1. Enter value directly....or
or	2. Calculate by filling in grey
0.02	cells below. (To restore formulas, hit button below).
Variable*	Data used directly in model.
20	Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	298.0	(ft/yr)
or		or	
Hydraulic Conductivity	K	3.6E-02	(cm/sec)
Hydraulic Gradient	i	0.0016	(ft/ft)
Porosity	n	0.2	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	24.5	(ft)
Transverse Dispersivity*	alpha y	2.4	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or		or	
Estimated Plume Length	Lp	1000	(ft)

3. ADSORPTION

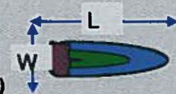
Retardation Factor*	R	1.0	(-)
or		or	
Soil Bulk Density	rho	1.7	(kg/l)
Partition Coefficient	Koc	1000	(L/kg)
FractionOrganicCarbon	foc	5.7E-6	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	1.1E+0	(per yr)
or		or	
Solute Half-Life	t-half	0.63	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	0	(mg/L)
Delta Nitrate*	NO3	0	(mg/L)
Observed Ferrous Iron*	Fe2+	0	(mg/L)
Delta Sulfate*	SO4	0	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	4000	(ft)
Modeled Area Width*	400	(ft)
Simulation Time*	25	(yr)



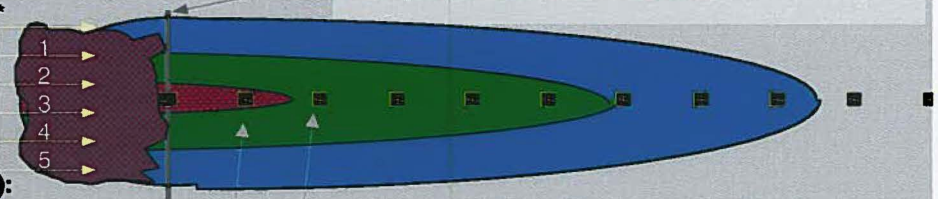
6. SOURCE DATA

Source Thickness in Sat.Zone* 7 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
42	0.05
60	0.3
192	6.486
60	0.3
42	0.05



View of Plume Looking Down

Source Halflife (see Help):

50	50	(yr)
Inst. React.	1st Order	
Soluble Mass	990	(Kg)
In Source Soil porewater		

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	400	800	1200	1600	2000	2400	2800	3200	3600	4000

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | View Output

RUN ARRAY | View Output

Help

Recalculate This

Paste Example Dataset

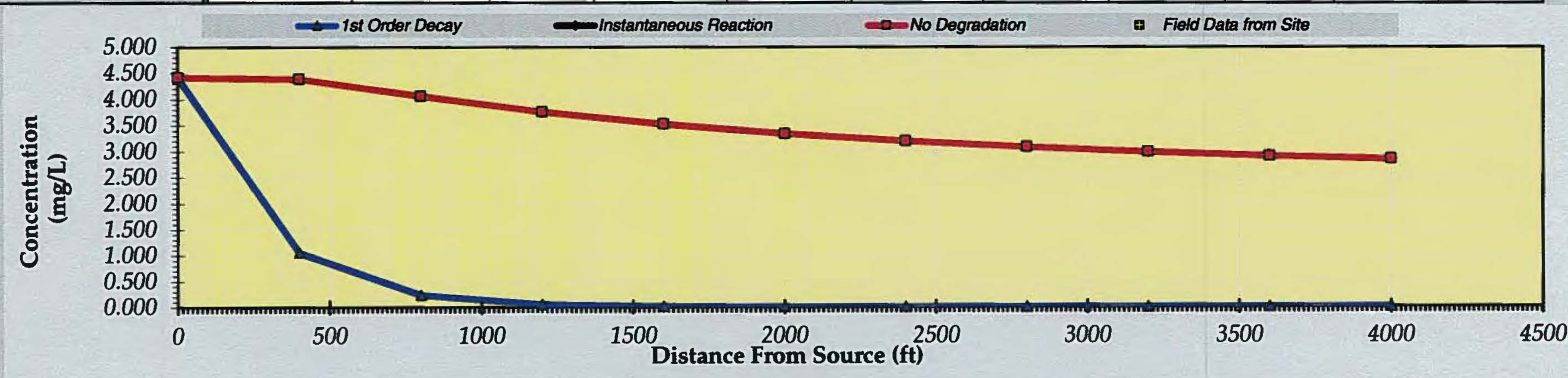
Restore Formulas for Vs,

CAL RUN 6 Input

LOWER PLUME CHROMIUM CONCENTRATION ALONG PLUME CENTERLINE AT END OF CPS RXN (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	400	800	1200	1600	2000	2400	2800	3200	3600	4000
No Degradation	4.421	4.388	4.063	3.762	3.526	3.342	3.196	3.080	2.986	2.909	2.845
1st Order Decay	4.421	1.056	0.235	0.052	0.012	0.003	0.001	0.000	0.000	0.000	0.000
Inst. Reaction	4.421	4.388	4.063	3.762	3.526	3.342	3.196	3.080	2.986	2.909	2.845
Field Data from Site											



Calculate Animation

Time:

25 Years

Return to

Recalculate This

RUN 6 INPUT, PREDICTED DISSOVLVED CHROMIUM CONCENTRATIONS IN PLUME AT END OF CPS RXN (mg/L at Z=0)

Transverse Distance (ft) ↓ \ Distance from Source (ft)	0	400	800	1200	1600	2000	2400	2800	3200	3600	4000
200	0.000	0.020	0.016	0.006	0.002	0.001	0.000	0.000	0.000	0.000	0.000
100	0.204	0.527	0.131	0.032	0.008	0.002	0.000	0.000	0.000	0.000	0.000
0	4.421	1.056	0.235	0.052	0.012	0.003	0.001	0.000	0.000	0.000	0.000
-100	0.204	0.527	0.131	0.032	0.008	0.002	0.000	0.000	0.000	0.000	0.000
-200	0.000	0.020	0.016	0.006	0.002	0.001	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	4.2E+4	7.0E+3	1.7E+3	4.2E+2	1.0E+2	2.5E+1	6.0E+0	1.5E+0	3.6E-1	8.6E-2	2.1E-2

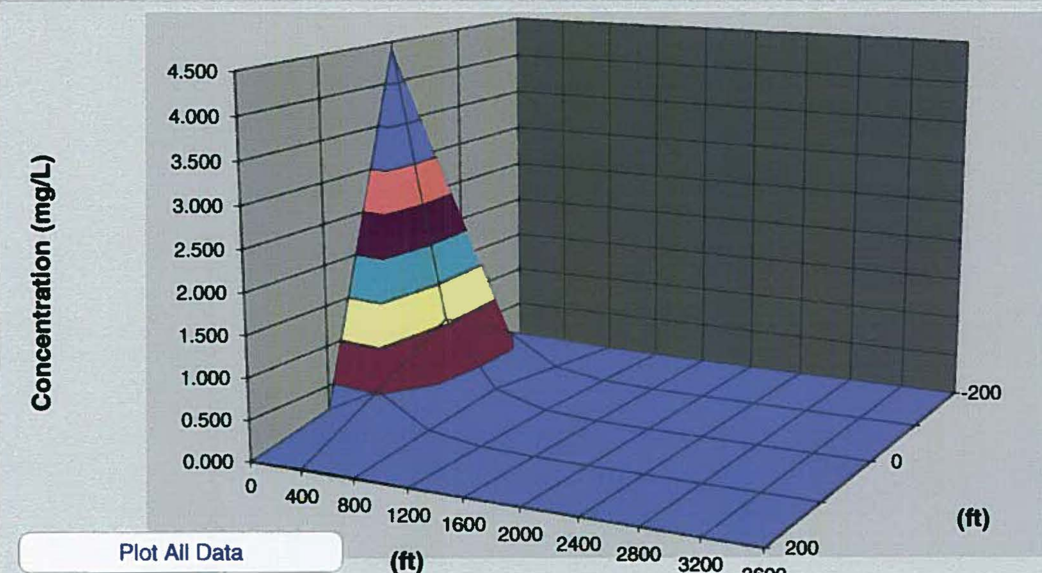
Model to Display:

No Degradation

1st Order Decay

Instantaneous

Time: **25 Years** Target Level: **0.070** mg/L Displayed Model: **1st Order Decay**



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	315.2	*(Kg)*
- Actual Plume Mass	16.3	*(Kg)*
= Plume Mass Removed by Biodeg	**298.9**	*(Kg)* (95 %)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	990.0	*(Kg)*
Contam. Mass in Source Now (t=25Years)	674.8	*(Kg)*
Current Volume of Groundwater in Plume	27.0	*(ac-ft)*
Flowrate of Water Through Source Zone	3.792	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

Run 6 Cal Input Parameters for Lower Aquifer, Predicted Chromium Concentrations Post CPS - MNA RTF

Lower Cr Plume
Shield Alloy
Run Name

Data Input Instructions:

115 → 1. *Enter value directly....or*
or 2. *Calculate by filling in grey*
0.02 *cells below. (To restore formulas, hit button below).*

Variable* → *Data used directly in model.*
20 → *Value calculated by model. (Don't enter any data).*

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	298.0	*(ft/yr)*
or		or	
Hydraulic Conductivity	*K*	3.6E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.0016	*(ft/ft)*
Porosity	*n*	0.2	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	24.5	*(ft)*
Transverse Dispersivity*	*alpha y*	2.4	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		or	
Estimated Plume Length	*Lp*	1000	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	1.0	*(-)*
or		or	
Soil Bulk Density	*rho*	1.7	*(kg/l)*
Partition Coefficient	*Koc*	1000	*(L/kg)*
FractionOrganicCarbon	*foc*	5.7E-6	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	1.0E+0	*(per yr)*
or		or	
Solute Half-Life	*t-half*	0.69	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	1600	*(ft)*
Modeled Area Width*	400	*(ft)*
Simulation Time*	272	*(yr)*

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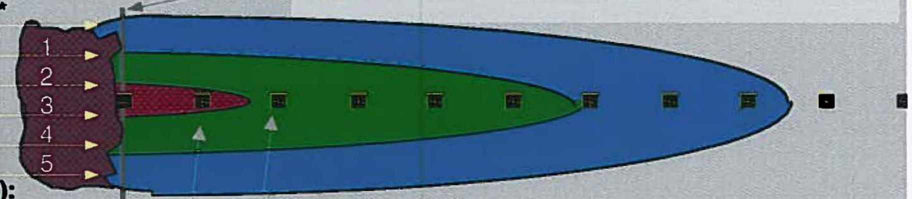
6. SOURCE DATA

Source Thickness in Sat.Zone* 7 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
42	0.0469
60	0.151
192	4.421
60	0.151
42	0.0469



View of Plume Looking Down

Source Halflife (see Help):

Inst. React.	1st Order	
50	50	*(yr)*

Soluble Mass 675 *(Kg)*
In Source Soil porewater

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	160	320	480	640	800	960	1120	1280	1440	1600

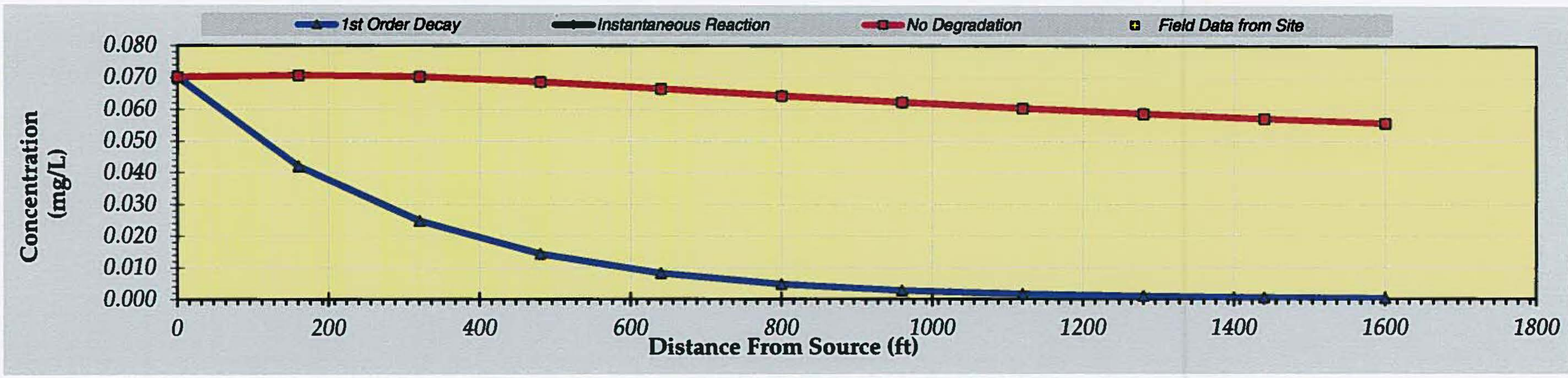
8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | **RUN ARRAY** | **Help** | Recalculate This

View Output | **View Output** | Paste Example Dataset

Restore Formulas for Vs,

Centerline Output



CAL RUN 6 INPUT, PREDICTED DISSOLVED CHROMIUM CONCENTRATIONS IN PLUME POST CPS RXN - MNA RTF (mg/L at Z=0)

Transverse Distance (ft) / **Distance from Source (ft)**

	0	160	320	480	640	800	960	1120	1280	1440	1600
200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.002	0.019	0.012	0.007	0.004	0.003	0.002	0.001	0.001	0.000	0.000
0	0.070	0.042	0.025	0.014	0.008	0.005	0.003	0.002	0.001	0.001	0.000
-100	0.002	0.019	0.012	0.007	0.004	0.003	0.002	0.001	0.001	0.000	0.000
-200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	2.8E+4	2.6E+2	1.6E+2	9.6E+1	5.7E+1	3.4E+1	2.1E+1	1.2E+1	7.3E+0	4.4E+0	2.6E+0

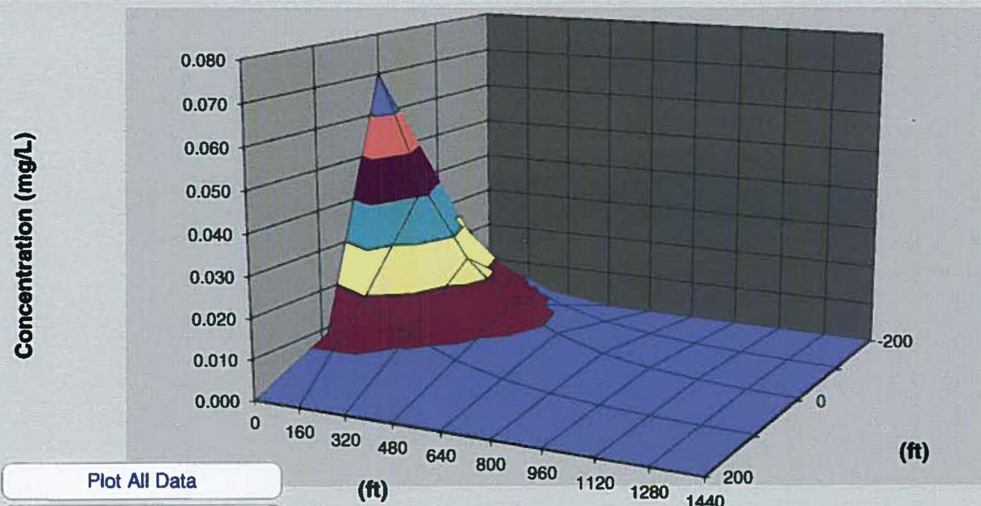
Time: **272 Years** Target Level: **0.070** mg/L Displayed Model: **1st Order Decay**

Model to Display:

No Degradation

1st Order Decay

Instantaneous



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	Can't Calc.	*(Kg)*
- Actual Plume Mass	Can't Calc.	*(Kg)*
= Plume Mass Removed by Biodeg	-	*(Kg)*

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	674.8	*(Kg)*
Contam. Mass in Source Now (t=272Years)	10.7	*(Kg)*
Current Volume of Groundwater in Plume	Can't Calc.	*(ac-ft)*
Flowrate of Water Through Source Zone	Can't Calc.	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

Run 7 Cal Parameters for Lower Aquifer Predicted Chromium Concentrations at End of CPS Reactivity

Lower Cr Plume
Shield Alloy
Run Name

Data Input Instructions:

115	1. Enter value directly....or
or	2. Calculate by filling in grey
0.02	cells below. (To restore formulas, hit button below).
Variable*	Data used directly in model.
20	Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	158.9	*(ft/yr)*
or		or	
Hydraulic Conductivity	*K*	2.4E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.0016	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	24.5	*(ft)*
Transverse Dispersivity*	*alpha y*	2.4	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		or	
Estimated Plume Length	*Lp*	1000	*(ft)*

3. ADSORPTION

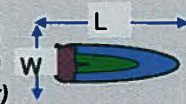
Retardation Factor*	*R*	1.0	*(-)*
or		or	
Soil Bulk Density	*rho*	1.7	*(kg/l)*
Partition Coefficient	*Koc*	1000	*(L/kg)*
FractionOrganicCarbon	*foc*	5.7E-6	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	1.1E+0	*(per yr)*
or		or	
Solute Half-Life	*t-half*	0.63	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	3000	*(ft)*
Modeled Area Width*	400	*(ft)*
Simulation Time*	25	*(yr)*



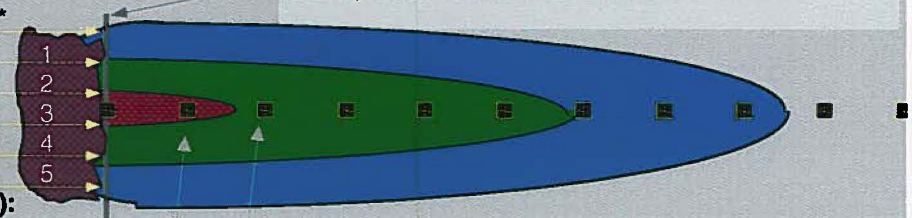
6. SOURCE DATA

Source Thickness in Sat.Zone* 7 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
42	0.05
60	0.3
192	6.486
60	0.3
42	0.05



View of Plume Looking Down

Source Halflife (see Help):

40	40	*(yr)*
Inst. React.	1st Order	

Soluble Mass 550 *(Kg)*
In Source Soil porewater

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	300	600	900	1200	1500	1800	2100	2400	2700	3000

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | **View Output**

RUN ARRAY | **View Output**

Help | Recalculate This

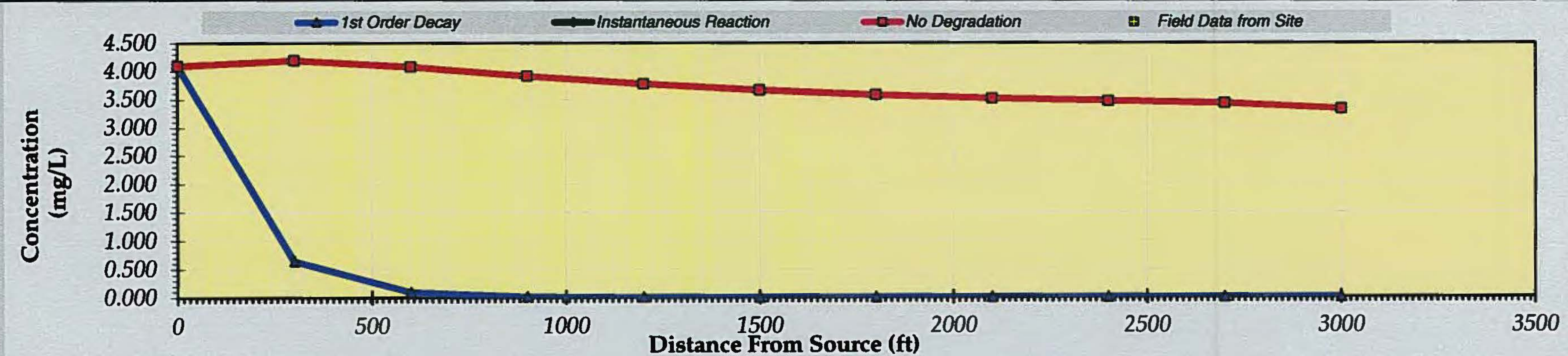
Paste Example Dataset

Restore Formulas for Vs,

CAL RUN 7 Input

.OWER PLUME DISSOLVED CHROMIUM CONCENTRATION ALONG PLUME CENTERLINE AT END OF CPS RXN (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	300	600	900	1200	1500	1800	2100	2400	2700	3000
No Degradation	4.095	4.196	4.079	3.915	3.773	3.662	3.578	3.515	3.470	3.426	3.328
1st Order Decay	4.095	0.646	0.097	0.014	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	4.095	4.196	4.079	3.915	3.773	3.662	3.578	3.515	3.470	3.426	3.328
Field Data from Site											



Calculate Animation

Time:

25 Years

Return to

Recalculate This Sheet

CAL RUN 7 INPUT, PREDICTED DISSOLVED CHROMIUM CONCENTRATIONS IN LOWER PLUME AT END OF CPS RXN (mg/L at Z=0)

Distance from Source (ft)

Transverse Distance (ft)	0	300	600	900	1200	1500	1800	2100	2400	2700	3000
200	0.000	0.008	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.189	0.314	0.051	0.008	0.001	0.000	0.000	0.000	0.000	0.000	0.000
0	4.095	0.646	0.097	0.014	0.002	0.000	0.000	0.000	0.000	0.000	0.000
-100	0.189	0.314	0.051	0.008	0.001	0.000	0.000	0.000	0.000	0.000	0.000
-200	0.000	0.008	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	2.8E+4	2.8E+3	4.5E+2	7.1E+1	1.1E+1	1.8E+0	2.8E-1	4.5E-2	7.1E-3	1.1E-3	1.8E-4

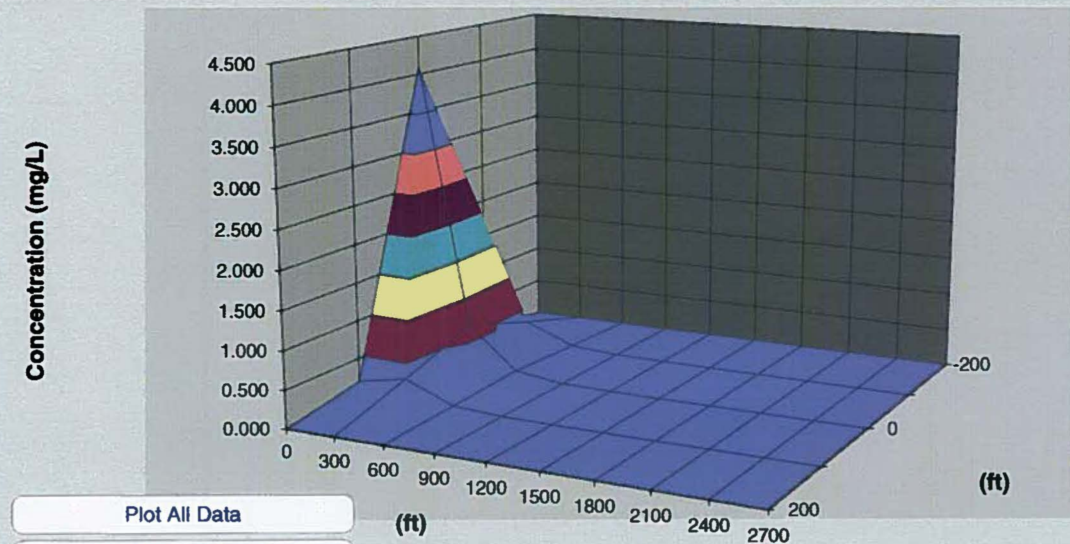
Time: **25 Years** Target Level: **0.070** mg/L Displayed Model: **1st Order Decay**

Model to Display:

No Degradation

1st Order Decay

Instantaneous



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	202.8	*(Kg)*
- Actual Plume Mass	7.4	*(Kg)*
= Plume Mass Removed by Biodeg	**195.3**	*(Kg)* (96 %)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	550.0	*(Kg)*
Contam. Mass in Source Now (t=25Years)	347.2	*(Kg)*
Current Volume of Groundwater in Plume	16.9	*(ac-ft)*
Flowrate of Water Through Source Zone	2.528	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

Run 7 Cal Parameters for Lower Aquifer Predicted Chromium Concentrations at Post CPS - MNA RTF

Lower Cr Plume
Shield Alloy
Run Name

Data Input Instructions:

115 — 1. Enter value directly....or
or
0.02 — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* — Data used directly in model.
20 — Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	158.9	(ft/yr)
or		or	
Hydraulic Conductivity	K	2.4E-02	(cm/sec)
Hydraulic Gradient	i	0.0016	(ft/ft)
Porosity	n	0.25	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	24.5	(ft)
Transverse Dispersivity*	alpha y	2.4	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or		or	
Estimated Plume Length	Lp	1000	(ft)

3. ADSORPTION

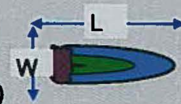
Retardation Factor*	R	1.0	(-)
or		or	
Soil Bulk Density	rho	1.7	(kg/l)
Partition Coefficient	Koc	1000	(L/kg)
FractionOrganicCarbon	foc	5.7E-6	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	6.3E-1	(per yr)
or		or	
Solute Half-Life	t-half	1.10	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	0	(mg/L)
Delta Nitrate*	NO3	0	(mg/L)
Observed Ferrous Iron*	Fe2+	0	(mg/L)
Delta Sulfate*	SO4	0	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	3000	(ft)
Modeled Area Width*	400	(ft)
Simulation Time*	223	(yr)



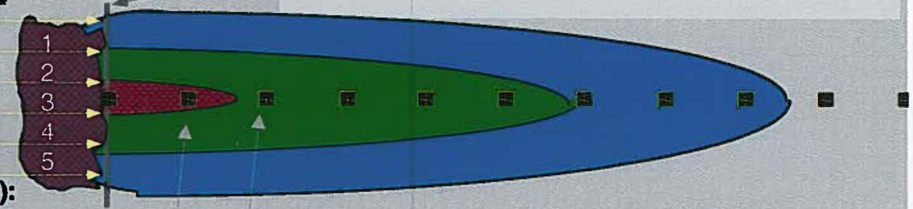
6. SOURCE DATA

Source Thickness in Sat.Zone* 7 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
42	0.043
60	0.14
192	4.095
60	0.14
42	0.043



View of Plume Looking Down

Source Halflife (see Help):

40	40	(yr)
Inst. React.	1st Order	

Soluble Mass 347 (Kg)
In Source Soil porewater

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	300	600	900	1200	1500	1800	2100	2400	2700	3000

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — View Output

RUN ARRAY — View Output

Help — Recalculate This

Paste Example Dataset

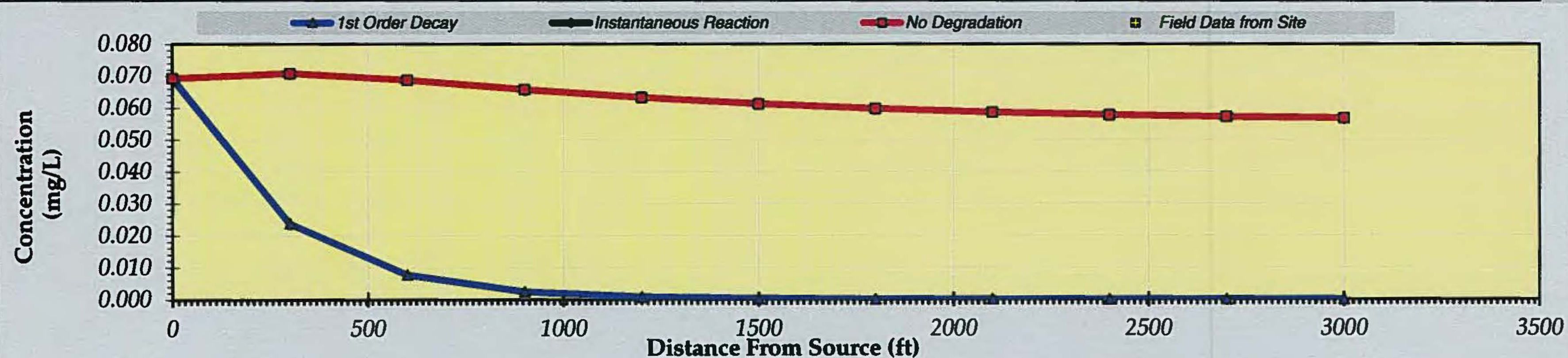
Restore Formulas for Vs,

CAL RUN 7 Input

LOWER PLUME CHROMIUM CONCENTRATION ALONG PLUME CENTERLINE POST CPS RXN - MNA RTF (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	300	600	900	1200	1500	1800	2100	2400	2700	3000
No Degradation	0.069	0.071	0.069	0.066	0.063	0.061	0.060	0.059	0.058	0.057	0.057
1st Order Decay	0.069	0.024	0.008	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	0.069	0.071	0.069	0.066	0.063	0.061	0.060	0.059	0.058	0.057	0.057
Field Data from Site											



Calculate Animation

Time:

223 Years

Return to

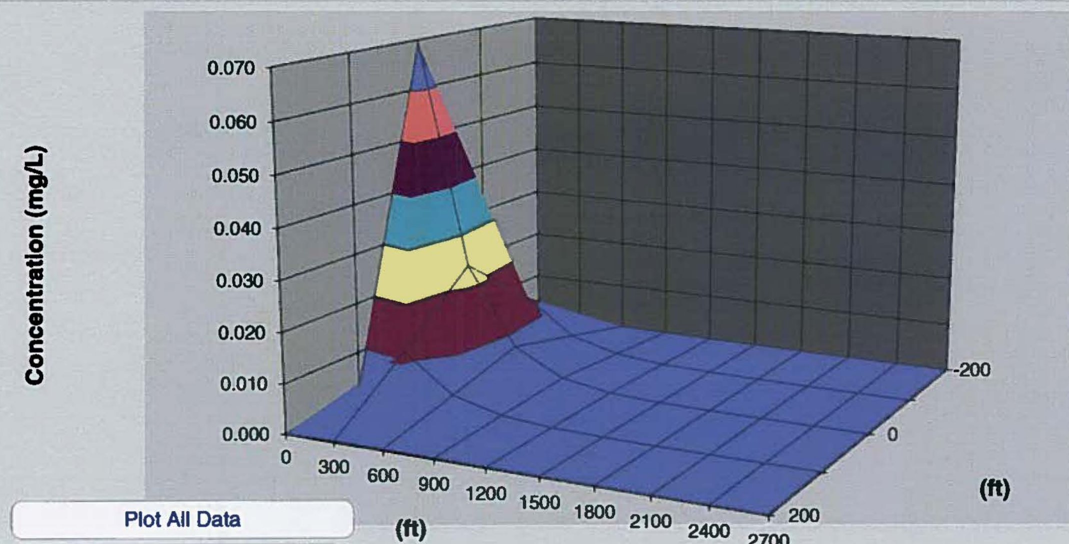
Recalculate This Sheet

CAL RUN 7 INPUT, PREDICTED CHROMIUM CONCENTRATIONS IN LOWER PLUME POST CPS RXN MNA RTF (mg/L at Z=0)

Model to Display: No Degradation | 1st Order Decay | Instantaneous

Transverse Distance (ft) ↓ / Distance from Source (ft)	0	300	600	900	1200	1500	1800	2100	2400	2700	3000
200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.002	0.011	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0	0.069	0.024	0.008	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000
-100	0.002	0.011	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	1.7E+4	1.0E+2	3.5E+1	1.2E+1	4.3E+0	1.5E+0	5.1E-1	1.7E-1	6.0E-2	2.1E-2	7.1E-3

Time: **223 Years** Target Level: **0.070** mg/L Displayed Model: **1st Order Decay**



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation: Can't Calc. *(Kg)*

- Actual Plume Mass: Can't Calc. *(Kg)*

= Plume Mass Removed by Biodeg: - *(Kg)*

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years): 347.0 *(Kg)*

Contam. Mass in Source Now (t=223Years): 5.9 *(Kg)*

Current Volume of Groundwater in Plume: Can't Calc. *(ac-ft)*

Flowrate of Water Through Source Zone: Can't Calc. *(ac-ft/yr)*

Mass HELP

Recalculate

Appendix C

Summary of Calculations of
Time to Reduce Trichloroethene Concentrations
Below NJDEP GWQS
Shieldalloy Site
Newfield, New Jersey

Problem Statement: Estimate the following:

1. The time to reduce the concentration of trichloroethene (TCE) detected in groundwater in the Lower Zone of the aquifer at the Shieldalloy Metallurgical Corporation (SMC) Site to the 1 microgram per liter (μg/L) New Jersey Department of Environmental Protection (NJDEP) Groundwater Quality Standard (GWQS) through monitored natural attenuation (MNA).

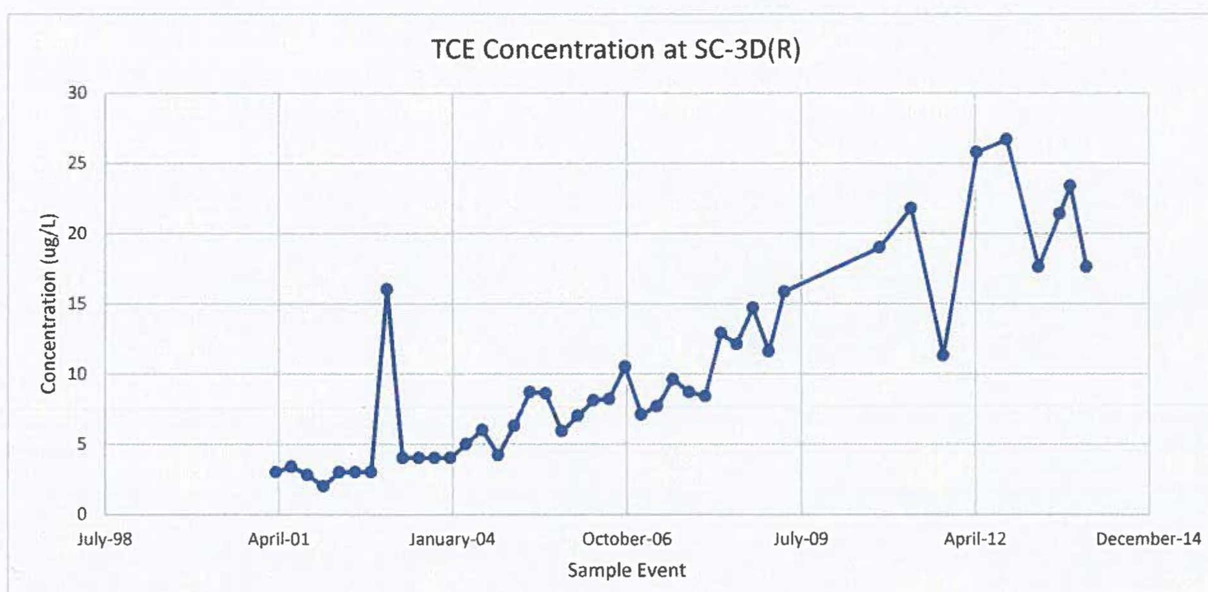
2. The time that would have been required for groundwater extraction to reduce concentrations of TCE in shallow groundwater at the SMC Facility in the former metals degreasing area near SC-20S to the NJDEP GWQS.

3. The time required for MNA to reduce residual concentrations of TCE between the EVO Injection Area and Well SC-38I below the NJDEP GWQS after completing remediation of the source area around well SC-20S by EVO injection.

Conceptual Site Understanding

The SMC Site is located in an area of commercial/industrial development. Solvent use by several area businesses has resulted in the release of TCE to groundwater. A former metals degreasing area located near monitoring well SC-20S in the north-central part of the SMC Facility was identified as the source of TCE to this well, which is shown on **Figure 1**. The TCE degreasing unit was taken out of service in 1967. The releases at the former degreasing area impacted shallow groundwater (approximately the upper 40 feet of the aquifer) in and downgradient of the area of SC-20S. In 2011, Emulsified Vegetable Oil (EVO) was injected into the groundwater in this area to address TCE impacts through in-situ biodegradation. The concentrations of TCE in shallow groundwater in this source area has been reduced to the NJDEP GWQS. The remaining residual concentrations of TCE that are above the GWQS are located at the southwest corner of the Site and extend from the Layne Well to Well SC-38I at the Car Wash (see **Figure 1**).

Off-site sources of chlorinated volatile organic compounds have also caused impact to groundwater downgradient of the SMC facility. Off-site sources of TCE impact to groundwater include, but are not limited to, Wheaton-Industries and Andrews Glass/Fischer & Porter Company Electronics Division, and Dauito's Express/Budget Truck Repair, which are located immediately downgradient or cross gradient of the SMC Facility. Elevated concentrations of TCE were also detected at Well SC-29D and at vertical profile location VP-3 immediately downgradient of the LaCroce Property south of the SMC Facility. Releases of TCE to groundwater from these off-site sources have migrated downgradient to the area of the Farm Parcel in the Lower Zone of the aquifer. As a result of these TCE releases and historical operation of the groundwater extraction system, the lower TCE plume has been bifurcated at the Care Wash resulting in a split plume as shown on **Figure 2**. One area is located at the southwest corner of the SMC property and extends downgradient to the Car Wash. The second area is located downgradient of the Car Wash and extends beneath and south of the Farm Parcel, with the highest concentrations most recently detected in wells SC-1D, SC-3D(R), and SC-34D. It is significant to note that in 2004, TCE concentrations began rising at SC-3D(R) and peaked in 2012 as shown below. Subsequently, TCE concentrations at this well appear to be decreasing indicating that much of the contamination upgradient of this location and well SC-34D to the south has been flushed from the aquifer.



Summary of Calculations of
Time to Reduce Trichloroethene Concentrations
Below NJDEP GWQS
Shieldalloy Site
Newfield, New Jersey

APPROACH FOR PROBLEM STATEMENT #1: Estimate Timeframe to Reduce TCE Below NJDEP GWQS In Lower Zone of Aquifer:

The BIOSCREEN Model was used to simulate the time to reduce TCE in groundwater in the Lower Zone of the aquifer below the NJDEP GWQS. BIOSCREEN is a computer model developed to simulate advective-reactive transport and natural attenuation of dissolved contaminants in groundwater and has been endorsed by the United States Environmental Protection Agency (EPA). The model accounts for one-dimensional advection, three-dimensional dispersion, and linear adsorption. The model also accounts for physical and biological processes responsible for the attenuation of organic parameters through use of a 1st order decay coefficient. The analytical equations and assumptions used in the model to simulate contaminant transport and attenuation have been previously documented in a Technical Memorandum to EPA entitled "SMC MNA Model" dated May 28, 2013 as has the conceptual hydrogeologic model that is the basis of input for TCE modeling simulations.

The following summarizes how the BIOSCREEN Model was used to estimate the timeframe to achieve the 1 μg/L GWQS for TCE.

Input for parameters used by the model were developed using site-specific data supplemented by representative data from literature sources for specific parameters when site-specific data was not available. The input data set was used to reproduce TCE results at a monitoring well located downgradient of a simulated TCE line source in the Lower Zone of the aquifer to "calibrate" the model. Once calibrated, the simulation time was incrementally increased using the calibrated model until concentrations of TCE throughout the plume and modeled area downgradient of the simulated source were below the 1 μg/L GWQS. For the model simulations, SC-35D was assumed to be the compliance point.

The following provides details of the simulations that were performed to assess the remediation timeframe for TCE in the Lower Zone of the aquifer:

A line source was simulated across a transect of the plume at the Farm Parcel extending through well locations SC-3D(R) and SC-34D (see **Figure 2**). This location was selected in part because it appears that concentrations recently peaked at this area as described above, and elevated concentrations of TCE were detected at these two monitoring wells during the most recent semiannual groundwater sampling event and in well SC-1D located downgradient of these wells making this a logical location to simulate a source. The average concentration of TCE detected at well SC-34D in 2009 following its installation was used as the initial source concentration to simulate the TCE concentration detected both at this well and well SC-1D approximately 4 years later (October 2013). The calibrated model was used to estimate the time to achieve the GWQS by incrementally increasing the simulation time until TCE concentrations were less than 1 μg/L throughout the modeled area (area between the line source and well SC-35D).

Model Input

Specific parameters required by the BIOSCREEN Model include the following:

Seepage velocity
Longitudinal, transverse, and vertical dispersivity
Retardation Factor
1st Order Decay Coefficient
Simulation Time
Line source dimensions and concentrations
Line source thickness; and
Soluble source mass

Input data for these parameters used to calibrate the model and perform the simulations described above are summarized below along with the basis and source of the data used for the individual parameters:

Input Parameter	Site Specific Range	Input for Simulation	Source of Data/Rationale
Lower Aquifer			
Advection Parameters			
Hydraulic Conductivity	64 to 137 feet/day	110	Range of hydraulic conductivity is based upon transmissivity calculated from drawdown data at SC-6D during pumping of RW-6D and saturated thickness of 55 feet.
Horizontal Hydraulic Gradient	0.0016	0.0016	Hydraulic Gradient measured downgradient of pumping well at Farm Parcel in April 2012. Refer to Technical Memorandum entitled SMC MNA Model, May 28, 2013.
Effective Porosity	0.1 to 0.3	0.2	Range in literature for sand - Walton, 1991. Principles of Groundwater Engineering. Lewis Publishers, Boca Raton, FL
Seepage Velocity	125 to >300 feet/yr	321	Calculated from hydraulic conductivity, hydraulic gradient, and effective porosity.

**Summary of Calculations of
Time to Reduce Trichloroethene Concentrations
Below NJDEP GWQS
Shieldalloy Site
Newfield, New Jersey**

Input Parameter	Site Specific Range	Input for Simulation	Source of Data/Rationale
Dispersion Parameters			
Longitudinal Dispersivity	21.8 to 55.1 feet	21.8	Calibration parameter based upon plume scale. For calibration and assuming plume extended from line source to SC-1D, used 21.8 feet. To simulate time to achieve 1 µg/L throughout simulation area (i.e., from simulated line source to SC-35D, a distance of 9,800 feet), used 55.1 feet.
Transverse Dispersivity	2.2 to 5.5 feet	2.2	1/10th of Longitudinal Dispersivity
Vertical Dispersivity	0 to 0.6 feet	0	Assumed no vertical dispersivity for conservatism.
Sorption Parameter			
Retardation Factor	1.08 to 2.4	1.1	Used low end of site specific range to reproduce TCE concentrations at SC-34D and SC-1D during calibration. For calculation of site-specific retardation factor, see Attachment A.
Biodegradation Parameter			
1st Order Decay Coefficient	---	0.09	Based upon low concentration of cis-1,2-dichloroethene, some natural biodegradation is occurring at site. Used as calibration parameter to reproduce TCE concentrations at SC-34D and SC-1D.
General Parameters			
Simulation Time	4 years	4	Elapsed time between initial concentration detected at SC-34D (line source) and simulated concentration detected 4 years later at this well and at SC-1D (October 2013).
Source Data			
Line Source Thickness	10 to 20 feet	10	Vertical profiling of groundwater indicates that sources do not extend over large vertical thickness of aquifer. Source thickness between 10 to 20 feet reasonable. Use as calibration parameter to reproduce concentrations at SC-1D and SC-34D.
	Plume Width (feet)	Concentration (mg/L)	
	167 feet	0.0005	Represents concentrations across simulated line source extending across width of plume through wells SC-3D(R) and SC-34D. The widths of 167 feet and 150 feet and associated concentrations are for one half of the symmetric plume (see **Figure 2**). The width of 1,383 feet represents the core of the plume and the assigned concentration represents the approximate average concentration of TCE detected in SC-34D in 2009 provided on Figure 2-14 of the OU1 Supplemental Remedial Investigation Report prepared by TRC in 2011.
	150 feet	0.006	
	1383 feet	0.042	
Soluble Mass	8 kilograms	8 kilograms	The TCE mass was estimated using groundwater concentrations and a partitioning coefficient for TCE with the linear partitioning equation to calculate an average soil concentration for TCE. This concentration was applied to the thickness of the plume to estimate source mass. The calculations are provided as Attachment B.

Based upon simulations performed using the calibrated BIOSCREEN Model using the input parameters identified above, **the time to attenuate the TCE mass at and upgradient of the Farm Parcel to the 1 µg/L GWQS in the Lower Zone of the aquifer was predicted to be approximately 35 years.** This timeframe does not account for TCE mass associated with any off-site releases downgradient of the Farm Parcel. Copies of the model simulations are provided as Attachment C.

APPROACH FOR PROBLEM STATEMENT #2: Estimate Timeframe to Reduce TCE Below NJDEP GWQS In Upper Zone of Aquifer from Pump and Treat in the Absence of EVO Injections

The US EPA Batch Flushing Model (EPA, 1988) developed by Gelhar and Wilson (1974) was used to estimate the time that would have been required to reduce the concentrations of TCE in the Upper Aquifer associated with historical releases from the former metals degreasing area if EVO was not injected in the source area around well SC-20S and groundwater extraction had continued as the remedy. The Batch Flushing Model is based upon the following analytical equation:

$$PV = - R * LN(C_s/C_i) \qquad \textit{(equation 1)}$$

Where:

PV = The number of pore volumes of clean groundwater that must flow through the contaminated part of an aquifer to reduce the concentration of a contaminant (C_i) to a concentration-based cleanup level (C_s); and

R = The retardation factor for the contaminant of interest (dimensionless).

$$t_{pv} = V_{pv}/Q \qquad \textit{(equation 2)}$$

Where:

t_{pv} = Time to move one pore volume of clean groundwater through the contaminated portion of the aquifer;

V_{pw} = Volume of contaminated groundwater contained in one pore volume = $L_{plume} * w_{plume} * b_{plume} * n$, (length^3);

Q = Groundwater extraction rate (length^3/time);

L_{plume} = The length of the plume defined by the GWQS, (length);

w_{plume} = The average width of the plume defined by the GWQS, (length);

b_{plume} = Saturated thickness of contaminated part of the aquifer (length);

n = Total porosity of the aquifer.

$$t_s = PV * t_{pv} \qquad \textit{(equation 3)}$$

t_s = Time to achieve cleanup criterion via groundwater extraction.

Assumptions:

The Batch Flushing model is subject to the following assumptions.

1. There is no ongoing source of contamination to the aquifer (i.e., there is no non-aqueous phase liquid present, source material has been removed, and contamination is present solely in a dissolved phase). This assumption is considered to be reasonable based upon the concentrations of TCE and other chlorinated VOCs that have been detected in groundwater.

2. The aquifer is homogeneous and isotropic and there are no heterogeneities in the contaminated part of the aquifer implying that removal of the contaminant of interest from the pore space is uniform and reverse matrix diffusion from lower permeability zones is not significant.

3. Flushing is assumed to be 100 percent efficient in removing contaminants from the aquifer. Due to the presence of dead-end pore spaces and pore scale variation in porosity, flushing may not be 100 percent efficient. Therefore, estimates of the time to achieve the 1 µg/L NJDEP GWQS using the Batch Flushing Model may be underestimated.

4. Contaminant removal occurs only through pore water exchange (i.e., there are no losses due to volatilization or biodegradation). Low concentrations of daughter compounds (e.g., cis-1,2-dichloroethene) have been detected in groundwater in portions of the TCE plume indicating that limited biodegradation is occurring.

5. During pumping, groundwater is removed from the entire thickness of the aquifer via fully penetrating wells. Note that the Layne Well, which was used to extract groundwater from the Upper Zone of the aquifer at the SMC Facility, is not a fully-penetrating well. This well is screened from 43 to 48 feet below ground surface.

As an additional assumption, the analysis assumed that the entire TCE plume in the Upper Zone of the aquifer at the Facility was fully captured by the Layne Well.

Since aquifers are rarely homogeneous, contaminant removal by groundwater flushing is not 100 percent efficient. For this reason and additional considerations, EPA has recognized that the batch flushing model can underestimate the time required to attain numerical cleanup criteria using groundwater extraction. Consequently, the following adjustment was incorporated into the analysis to address the above assumptions and provide more representative estimates of the time to attain the NJDEP GWQS for TCE through groundwater extraction.

Summary of Calculations of
Time to Reduce Trichloroethene Concentrations
Below NJDEP GWQS
Shieldalloy Site
Newfield, New Jersey

Since the Layne Well is not fully screened across the entire saturated thickness of the contaminated zone, flow to the well is distorted and must flow along greater distances to reach the well screen than for a fully penetrating well. As a consequence, contaminants are not uniformly flushed over the entire thickness of the aquifer during pumping. To account for this inefficiency, an adjustment factor was applied to the groundwater extraction rate for the Layne Well based upon the proportion of the saturated thickness of the impacted zone (estimated to be approximately 40 feet) screened by this pumping well and considering the maximum specific capacity of the well.

Based upon an estimated impacted zone thickness of approximately 40 feet and using the maximum attainable specific capacity and percentage of the aquifer screened by a pumping well presented in Driscoll (1986), a adjustment factor of 4 was applied to the average pumping rate for the Layne Well (24 gallons per minute) based upon discharge measurements at this well during the period between 2011 and 2012. The basis for the correction factor is shown below.

Well	Screen Length, L (feet)	Well Radius, r (feet)	Thickness of Impacted Zone, b (feet)	b/r	% Impacted Zone Screened by Well
Layne Well	5	0.25	40	160	12.5%

Adjustment factor (AF) = Maximum Attainable Specific Capacity/Percent of Maximum Specific Capacity Attainable

From chart, percent of maximum specific capacity attained by Layne is 23 percent. Therefore, adjustment factor is estimated to be:

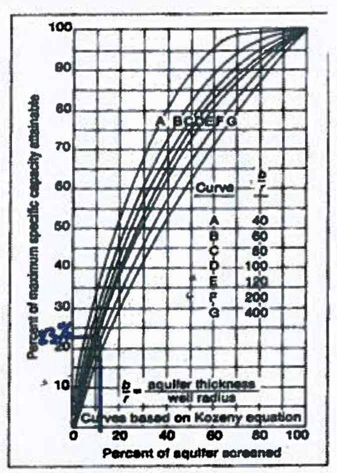


Figure 9.35. Relationship of partial penetration and attainable specific capacity for wells in homogeneous confined aquifers.

AF = 1.0/0.23 = 4.3

Calculations:

Input for Batch Flushing Model

1. The concentration of TCE used to model the number of pore volumes required to reduce TCE in the Upper Zone at the facility was based upon the geometric mean concentration of TCE detected in SC-20S in the former metals degreasing area during the period between 2001 and 2009 prior to injection of EVO. The most recent concentration prior to injection (April 2009) was also used to provide a lower end estimate of the time to achieve the GWQS. These data are summarized below.

Sampling Event	TCE Concentration (µg/L)	Sampling Event	TCE Concentration (µg/L)
Apr-01	98	Apr-06	681
Apr-02	35	Apr-07	496
Apr-03	280	Apr-08	39.7
Apr-04	220	Apr-09	67.4
Apr-05	56.5	Geomean	130

2. The remediation goal for TCE was assumed to be the 1 µg/L NJDEP GWQS.

3. The retardation factor for TCE used in the analysis was 1.1 based upon calculations provided as Attachment A.

4. The volume of impacted groundwater contained in one pore volume was based upon a plume length of 1,375 feet and average width of 369 feet based upon the TCE concentration distribution in shallow groundwater during April 2009. The plume dimensions are based upon the 1 µg/L TCE isoconcentration contour shown on **Figure 3**, which extends just upgradient of well SC-27S to approximately 270 feet downgradient of well K. The thickness of the impacted zone was estimated to be approximately 40 feet and the porosity of the aquifer sands was assumed to range from 0.3 to 0.45 (geometric mean of 0.37) based upon literature values presented in Walton (1991).

5. The average pumping rate for the Layne Well was calculated to be 24 gallons per minute (gpm) using measurements during the period from April 2011 to April 2012. This pumping rate was adjusted downward by a factor of 4 to account for flushing inefficiency due to partial penetration and minor variations in stratigraphy in the aquifer.

The following table summarizes calculations of the number of pore volumes required to reduce concentrations of TCE to the 1 µg/L GWQS using pre-EVO injection TCE concentrations detected at SC-20S.

Retardation Factor	Initial TCE Concentration (µg/L)	Target Remedial Goal (µg/L)	Number of Pore Volume Flushes Required
1.1	130	1	5.4
1.1	67.4	1	4.6

The following table summarizes calculations of the volume of impacted groundwater contained in one plume pore volume and the time required to achieve the TCE GWQS in the Upper Zone of the Facility through groundwater extraction from the Upper Zone using the existing groundwater extraction well screened in the Upper Zone at the Facility.

Plume Dimensions				Plume Volume		Adjusted Pumping Rate, Layne	Time to Remove One Pore Volume	Pore Volumes	Time to Reach Remediation Goal
Length (feet)	Average Width (feet)	Thickness (feet)	Total Porosity	(feet^3)	(gallons)	(gallons/day)	(days)	Required	(years)
1375	369	40	0.37	7509150	56168442	8640	6501	4.6	82
1375	369	40	0.37	7509150	56168442	8640	6501	5.4	96

Based upon the analysis above, the **time to reduce TCE in groundwater in the Upper Zone of the aquifer beneath the facility due to groundwater extraction, assuming full capture of the TCE plume by the Layne Well, was estimated to range from approximately 82 years to 96 years.**

APPROACH FOR PROBLEM STATEMENT #3: Estimate the Timeframe to Reduce Remaining Concentrations of TCE in Groundwater in the Upper Zone at the Southwest Corner of the Facility Between the the EVO Injection Area and Well SC-38I to below the NJDEP GWQS Post-EVO Remediation of Source around Well SC-20S.

The BIOSCREEN Model was used to estimate the time required to attenuate residual concentrations of TCE remaining at the southwest corner of the SMC Facility between the EVO injection area and Well SC-38I following remediation of the source area around well SC-20S through EVO injections. To perform the simulations, the average concentration of TCE observed in the Upper Zone of the aquifer during the most recent monitoring event in October 2013 between the Layne Well and SC-38I was used to calculate the remaining potential dissolvable mass of TCE sorbed onto soil in the Upper Zone downgradient of the Layne Well. In addition and to be conservative, it was assumed that additional TCE mass was present between the EVO injection area and the Layne Well. The average concentration of TCE (i.e. 25 µg/L) between the EVO injection area and the downgradient extent of the plume shown on **Figure 3** was used to conservatively estimate this additional mass. The combined mass from these two areas was assigned to a line source across the upgradient edge of the plume (**Figure 1**) near the Layne Well. Simulations were performed using site-specific input parameters and the simulation time was incrementally increased until concentrations throughout the plume and in the area between the Facility and the Farm Parcel attenuated below the GWQS. Input data used for the simulations including the source and rationale are presented below.

Summary of Calculations of
Time to Reduce Trichloroethene Concentrations
Below NJDEP GWQS
Shieldalloy Site
Newfield, New Jersey

Calculations by: JSH
Checked by NR

Input Parameter	Site Specific Range	Input for Simulation B	Input for Simulation C	Source of Data/Rationale
Upper Aquifer				
Advection Parameters				
Hydraulic Conductivity	42 to 133 feet/day	75	133	Range of hydraulic conductivity is based upon transmissivity calculated from drawdown data at wells B, C, I, and SC-9S during pumping test of Layne Well using an estimated saturated thickness of the upper zone of 80 feet. Run B represents the geomean hydraulic conductivity.
Horizontal Hydraulic Gradient	0.0016	0.0016	0.0016	Hydraulic Gradient measured downgradient of pumping well at Farm Parcel in April 2012. Refer to Technical Memorandum entitled SMC MNA Model, May 28, 2013. Considered to be representative of non-pumping hydraulic gradients.
Effective Porosity	0.25 to 0.35	0.3	0.25	Range in literature for medium to coarse gravelly sand - Walton, 1991.
Seepage Velocity	70 to 310	146	310	Calculated from range of hydraulic conductivity, hydraulic gradient, and effective porosity.
Dispersion Parameters				
Longitudinal Dispersivity	feet	23.7	23.7	Longitudinal dispersivity was estimated by the model based upon a plume length of 930 feet.
Transverse Dispersivity	feet	2.4	2.4	1/10th of Longitudinal Dispersivity
Vertical Dispersivity	feet	0	0	Assumed no vertical dispersivity for conservatism.
Sorption Parameter				
Retardation Factor	1.07 to 1.11	1.1	1.1	Calculated using fraction of organic carbon data from upper aquifer at STSB-1 and total porosity ranging from 0.3 to 0.45, representative of medium to coarse sand. For calculation of site specific retardation factor, see Attachment A.
Biodegradation Parameter				
1st Order Decay Coefficient	0.2 to 1.2	0.2	0.2	Based upon low concentration of cis-1,2-dichloroethene, some natural biodegradation is occurring at site. Attenuation factors were calculated using TCE concentration data from wells SC-3S and SC-1S. These calculations are provided as Attachment D. Used lowest value to be conservative.
General Parameters				
Simulation Time	NA	40	30	Time was incrementally increased until simulations indicated TCE had decreased below remediation goal of 1 µg/L.
Source Data				
Line Source Thickness	5 to 10 feet	10	7.5	Source thickness was estimated based upon the screen intervals of wells exhibiting the highest concentrations of TCE (Layne and SC-38I).
	Plume Width (feet)	Concentration (mg/L)		
	42 feet	0.003		Represents concentrations across simulated line source extending across width of plume near the Layne Well as shown on **Figure 1**. Note that the first two widths are for one side of the plume, and the last width increment represents the plume core.
	42 feet	0.0075		
	84 feet	0.016		
Soluble Mass	0.4 kg	0.4	0.4	The TCE mass was estimated using the average groundwater concentration within the plume between the EVO injection area and well SC-38I and and a partitioning coefficient for TCE to calculate an average soil concentration for TCE. This concentration was applied to the inferred volume of soil within the plume footprint to conservatively estimate source mass. The calculations are provided as Attachment B.

Calculations by: JSH
Checked by NR

Results of the BIOSCREEN modeling indicate that **residual TCE concentrations in the Upper Aquifer between the EVO injection area and Well SC-38I following remediation of the source near SC-20S through EVO injections should be reduced below the 1 µg/L NJDEP GWQS within a timeframe of between 30 years and 40 years, assuming off-site sources are no longer releasing TCE to groundwater.**

References:

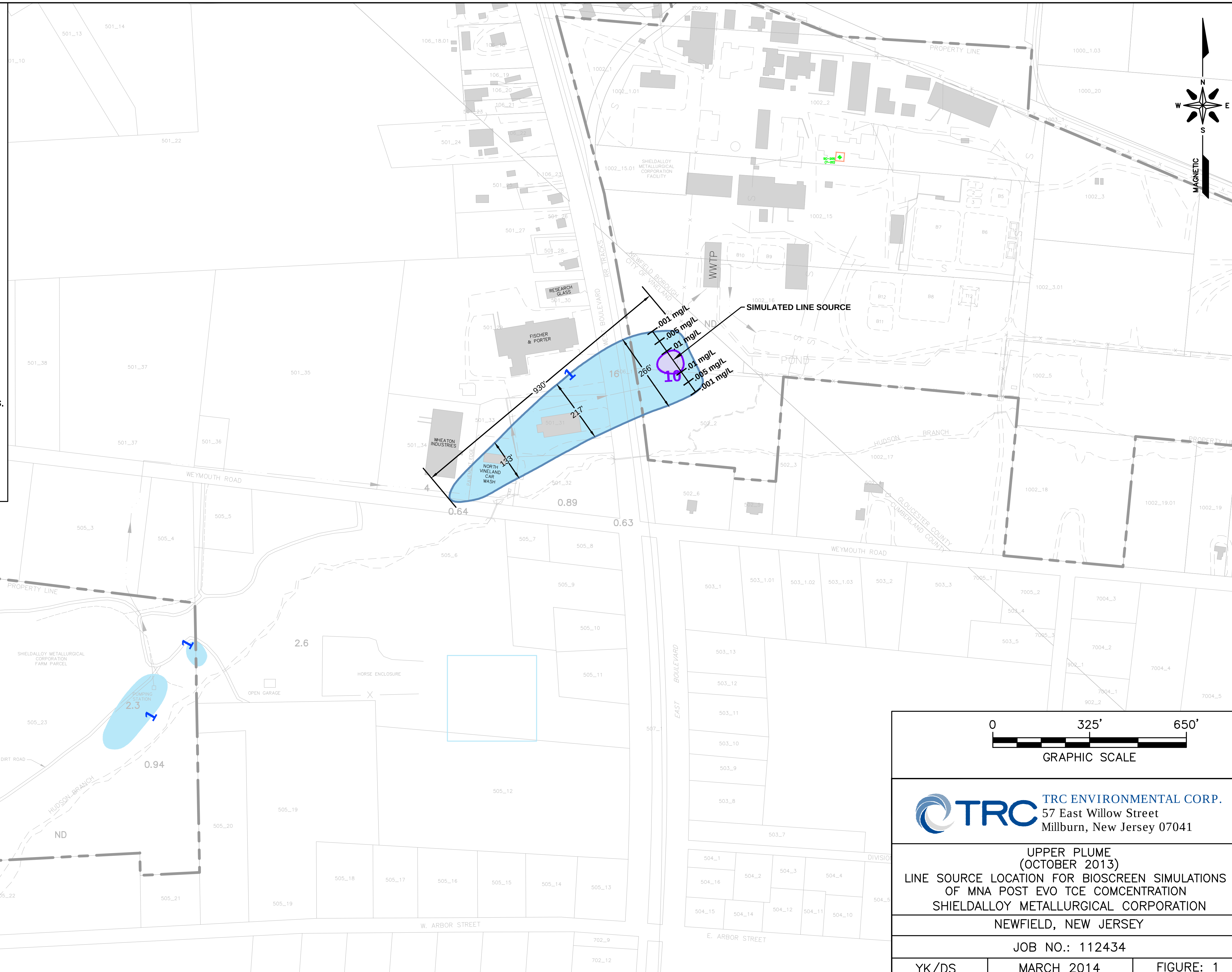
Driscoll, F.A., 1986. Groundwater and Wells. The Johnson Division, St. Paul, MN.

Walton, W.C., 1991 Principles of Groundwater Engineering. Lewis Publishers, Boca Raton, FL

USEPA, 1988. Guidance on Remedial Actions for Ground Water at Superfund Sites. EPA/540/G-88/003. OSWER Directive 9283.1-2, December 1988.

Appendix C

Figures



LEGEND

SHALLOW WELL
MONITORING WELL ID
SC-20S
(7-22) SCREENED INTERVAL (ft. bsg)
1.60 TCE CONCENTRATION IN PPB

FORMER SOURCE OF TCE [MANPRO-VIBRA DEGREASING UNIT (TCE USED FROM 1965-1967)]

TCE INTERMEDIATE CONCENTRATION KEY

- 1 – 10 ppb
- 10 – 50 ppb

NOTES:

1. BASE MAP FROM JAMES M. STEWART, INC., LAND SURVEYORS, PHILADELPHIA, PA.
2. LACROCE PROPERTY BOUNDARY BASED ON TAX MAP-CITY OF VINELAND, OCTOBER 1, 1971.
3. INTERMEDIATE INTERVAL RANGES FROM 30 FT BSF TO 80 FT BSG.
4. ND INDICATES NOT DETECTED
5. PPB INDICATES PARTS PER BILLION

0 325' 650'
GRAPHIC SCALE

TRC ENVIRONMENTAL CORP.
57 East Willow Street
Millburn, New Jersey 07041

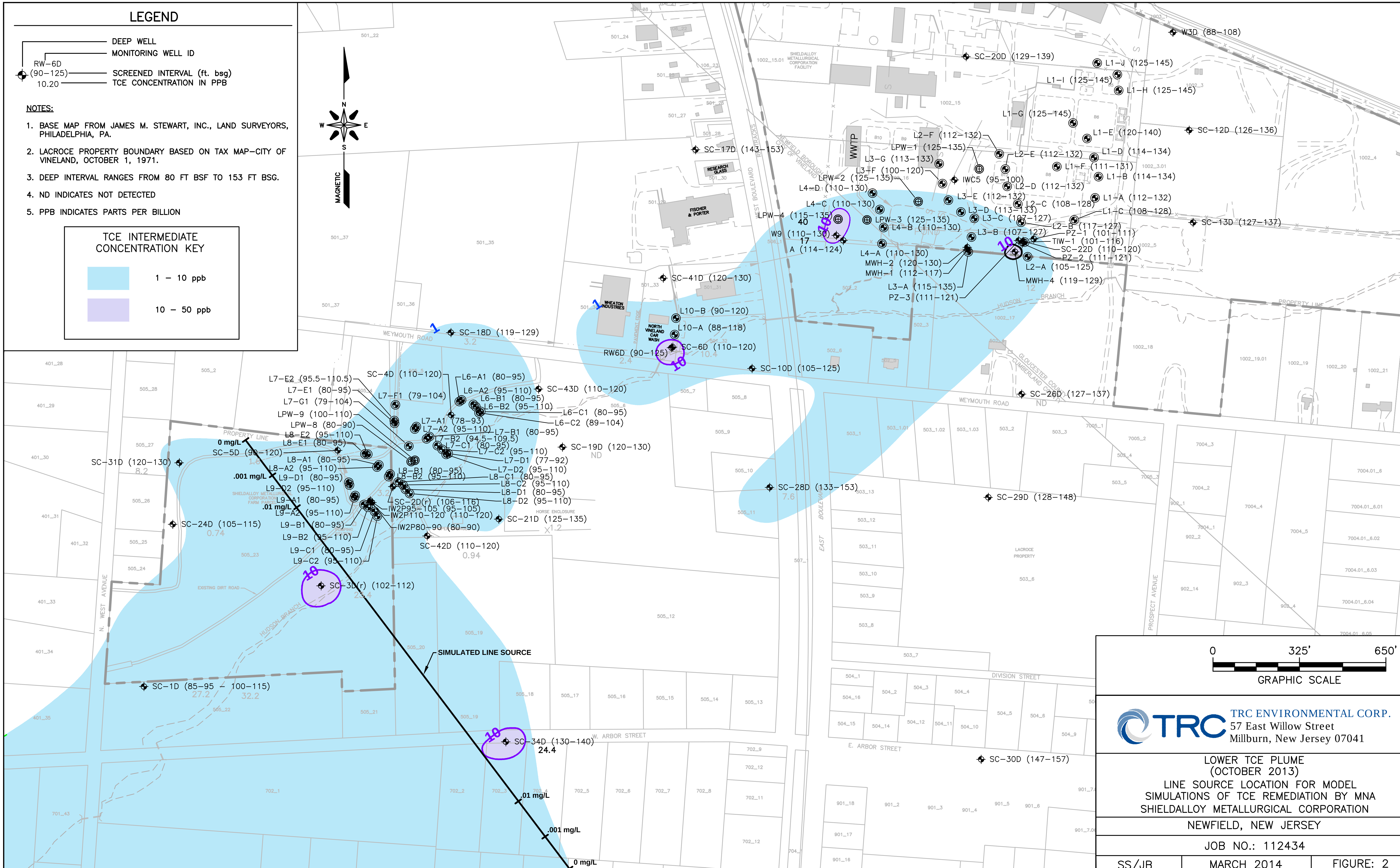
UPPER PLUME
(OCTOBER 2013)
LINE SOURCE LOCATION FOR BIOSCREEN SIMULATIONS
OF MNA POST EVO TCE COMCENTRATION
SHIELDALLOY METALLURGICAL CORPORATION

NEWFIELD, NEW JERSEY

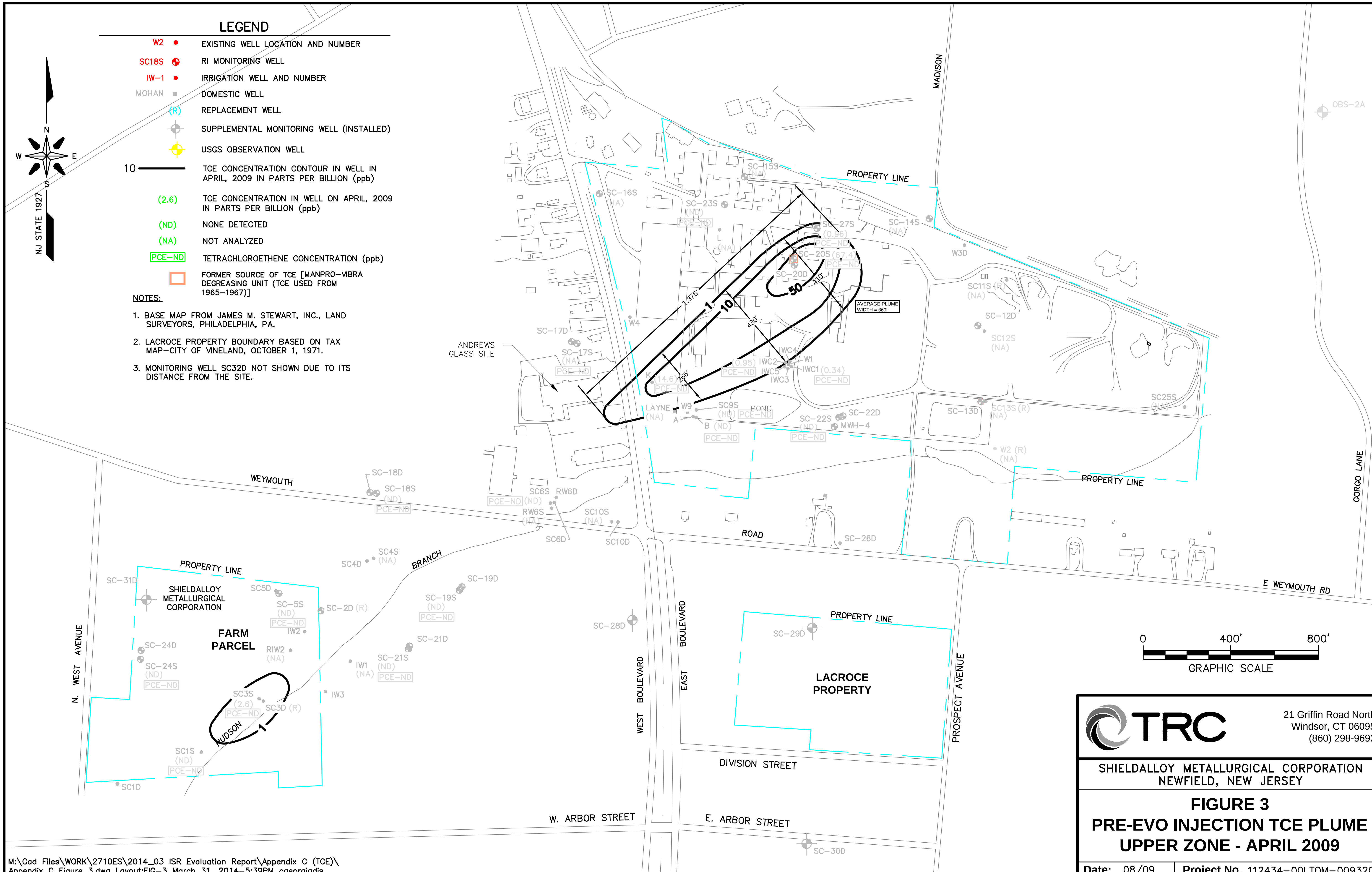
JOB NO.: 112434

YK/DS | MARCH 2014 | FIGURE: 1

FILE: M:\CAD FILES\WORK\2710ES\2014_03 ISR EVALUATION REPORT\APPENDIX C (TCE)\APPENDIX C FIGURE 1.DWG 03/31/14 05:02:02PM, cgeorgiadis, LAYOUT: TCE-INTERMEDIATE



FILE: \\MILLBURN-FP2\DRAFTINGFILES\CAD FILES\WORK\2710ES\2014_03 ISR EVALUATION REPORT\TCE GW RESULTS 4_2013 REV2-TM.DWG 03/31/14 01:47:06PM, mdraft, LAYOUT: TCE-DEEP



LEGEND

W2	EXISTING WELL LOCATION AND NUMBER
SC18S	RI MONITORING WELL
IW-1	IRRIGATION WELL AND NUMBER
MOHAN	DOMESTIC WELL
(R)	REPLACEMENT WELL
	SUPPLEMENTAL MONITORING WELL (INSTALLED)
	USGS OBSERVATION WELL
10	TCE CONCENTRATION CONTOUR IN WELL IN APRIL, 2009 IN PARTS PER BILLION (ppb)
(2.6)	TCE CONCENTRATION IN WELL ON APRIL, 2009 IN PARTS PER BILLION (ppb)
(ND)	NONE DETECTED
(NA)	NOT ANALYZED
PCE-ND	TETRACHLOROETHENE CONCENTRATION (ppb)
	FORMER SOURCE OF TCE [MANPRO-VIBRA DEGREASING UNIT (TCE USED FROM 1965-1967)]

NOTES:

1. BASE MAP FROM JAMES M. STEWART, INC., LAND SURVEYORS, PHILADELPHIA, PA.
2. LACROCE PROPERTY BOUNDARY BASED ON TAX MAP-CITY OF VINELAND, OCTOBER 1, 1971.
3. MONITORING WELL SC32D NOT SHOWN DUE TO ITS DISTANCE FROM THE SITE.

TRC

21 Griffin Road North
Windsor, CT 06095
(860) 298-9692

SHIELDALLOY METALLURGICAL CORPORATION
NEWFIELD, NEW JERSEY

FIGURE 3
PRE-EVO INJECTION TCE PLUME UPPER ZONE - APRIL 2009

Date: 08/09 **Project No.** 112434-00LTOM-009320

M:\Cad Files\WORK\2710ES\2014_03 ISR Evaluation Report\Appendix C (TCE)\
Appendix C Figure 3.dwg Layout:FIG-3 March 31, 2014-5:39PM cgeorgiadis

Appendix C

Attachments

ATTACHMENT A

CALCULATION OF TCE RETARDATION FACTORS

Attachment A
Calculation of Retardation Factors
for Trichloroethene
Shieldalloy Site
Newfields, New Jersey

Problem Statement:

Calculate retardation factors for Trichloroethene (TCE) in the Upper and Lower Zones of the aquifer using available organic carbon data and typical ranges for porosity and bulk density for sands and the organic carbon partitioning coefficient for TCE.

The retardation factor for TCE was calculated using the following Equation:

$$R = 1 + [(K_{oc} * f_{oc} * \rho_b)/n]$$

Where:

R = Retardation Factor (dimensionless).

K_{oc} = Organic Carbon Partitioning Coefficient for TCE (ml/g) - The Koc of TCE is 126 ml/g (Schwille, F., 1988. *Dense Chlorinated Solvents In Porous and and Fractured Media, Model Experiments*. Lewis Publishers, Chelsea, MI).

f_{oc} = Fraction of Organic Carbon in Soil (dimensionless).

ρ_b = Soil Dry Bulk Density, g/cm^3) - Estimate to be 1.85 g/cm^3 - Reasonable Estimate for consolidated sand at depth (Freeze, A. and J. Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, NJ).

n = Total Porosity (dimensionless) - Estimated to be 0.4, typical for a sand based upon literature values (Walton, W.C., 1991. Principles of Groundwater Engineering. Lewis Publishers, Boca Raton, FL) and consistent with porosity estimated during treatability testing.

Location	Depth (feet bgs)	Total Organic Carbon (mg/Kg)	Fraction of Organic Carbon	K_{oc} (ml/g)	ρ_b (g/cm^3)	n	R
Upper TCE Plume							
STSB-1	60 to 70	146	0.00015	126	1.85	0.3	1.11
			0.00015	126	1.85	0.46	1.07
Lower TCE Plume							
STSB-1	80 to 90	144	0.00014	126	1.85	0.4	1.08
	90 to 100	177	0.00018	126	1.85	0.4	1.10
	100 to 110	178	0.00018	126	1.85	0.4	1.10
	110 to 120	1260	0.0013	126	1.85	0.4	1.73
SC-2D®	106.5 to 107	2050	0.0021	126	1.85	0.4	2.19
MWH-4	122.5 to 123	2340	0.0023	126	1.85	0.4	2.36
		Geomean Lower Zone	0.00055				1.51

ATTACHMENT B

CALCULATION OF TCE MASS IN SOIL FOR BIOSCREEN SIMULATIONS

Attachment B
Calculation of TCE Mass In Soil
for BIOSCREEN Model Simulations
Shieldalloy Site
Newfield, New Jersey

Problem Statement:

Estimate the mass of trichloroethene (TCE) sorbed onto soils in the following areas for BIOSCREEN Modeling:

1 The Upper Zone near the southwest corner of the Shieldalloy Facility to estimate the timeframe for residual concentrations of TCE to decrease below the New Jersey Department of Environmental Protection (NJDEP) 1 µg/L Groundwater Quality Standard (GWQS); and

2. The Lower Zone in the area of wells SC-1D, SC-3D(R), and SC-34D near the Farm Parcel to simulate the time to reduce concentrations of TCE in the Lower Zone below the NJDEP GWQS.

Approach:

1. Potential sorbed concentrations of TCE in soil were estimated using the following equation.

$$K_d = = K_{oc} * f_{oc} = C_s/C_w$$

Where:

K_d = Distribution Coefficient (milliliters/gram);
C_s = Concentration of contaminant in soil (milligrams/gram); and
C_w = Concentration of contaminant in groundwater (milligrams/milliliter).
K_{oc} = Organic carbon partitioning coefficient forTCE = 126 ml/g - Schwille, F., 1988. Dense Chlorinated Solvents in Porous Media Model Experiments. Lewis Publishers, Chelsea, MI.

Using fraction of organic carbon data and organic carbon partitioning coefficient presented above, the distribution coefficient for the Upper and Lower Zones of the aquifer were calculated to be:

$K_d = K_{oc} * f_{oc} = 126$ ml/g $* 0.00015 = 0.019$ ml/g **Upper Zone**

$K_d = K_{oc} * f_{oc} = 126$ ml/g $* 0.00055 = 0.069$ ml/g **Lower Zone**

2. The estimated concentration in soil was used to estimate the mass of TCE using the following equation:

Mass = Volume of soil in plume or estimated source area (Length^3) * dry bulk density of the soil (Soil Mass/Length^3) * estimated TCE concentration in soil (Mass TCE/Mass Soil)

Attachment B
Calculation of TCE Mass In Soil
for BIOSCREEN Model Simulations
Shieldalloy Site
Newfield, New Jersey

Estimate of Soil Concentration and Soil Mass in Upper Zone At Southwest Corner of SMC Facility for BIOSCREEN Simulations to Estimate Time to Achieve GWQS

For the BIOSCREEN simulations, soluble TCE mass was assumed to be present in Upper Zone soils between the EVO injection area and the Layne Well, and in the area between the Layne Well and Well SC-38I. The following approach was used to account for TCE mass in these two areas. Injections of EVO occurred in the area immediately around SC-20S corresponding to the area defined by the 50 µg/L isocontour shown on **Figure 3** provided with these calculations. On this basis, the average TCE concentration between the downgradient extent of the 50 µg/L isocontour shown on this figure and the downgradient extent of the plume (i.e., approximately 25 µg/L) was used as the basis for estimating concentrations of TCE in soil in this area, which were in turn, used to estimate TCE mass. Likewise, to account for potential mass located between the Layne Well and SC-38I, the average concentration of TCE detected in these two wells during October 2013 was used. The TCE concentration detected at SC-38I during October 2013 was 4 µg/L and the concentration at the Layne Well was 16 µg/L yielding a average of 10 µg/L. The following table summarizes the calculation of TCE concentrations in soil in these areas used to estimate remaining TCE mass in the Upper Zone later in these calculations.

Area of Interest	K_d (ml/g)	C_w (mg/ml)	C_s	
			(mg/g)	(mg/Kg)
Area between EVO Injections and Layne Well	0.019	0.000025	0.0000005	0.0005
Area between Layne Well and SC-38I	0.019	0.00001	0.0000002	0.0002

The TCE mass was calculated using these predicted soil concentrations and following equation:

$$M_{TCE} = V_{soil} * \rho_b * C_s$$

Where: M_{TCE} = Estimated mass of TCE in soil, (mass);

V_{soil} = Volume of soil within area defined by 1 µg/L TCE isocontour ($length^3$). For the area between the EVO injection area and the Layne Well, this volume was calculated as the distance between the downgradient extent of the 50 µg/L and 1 µg/L isocontours shown on **Figure 3** provided with these calculations, the average width of the plume downgradient of the 50 µg/L isocontour, and a 40 foot thick impacted zone. For the area between the Layne Well and SC-38I, this volume was calculated based upon the length and average width of the plume as defined by the 1 µg/L isoconcentration contour shown on **Figure 1** provided with these calculations and a 40 foot thick impacted zone. It is understood that Figures 1 and 3 show concentrations of TCE from different monitoring events. **Figure 1** shows concentrations of TCE detected during October 2013, which reflects Post EVO injection in the source area. Since no data was available for shallow groundwater between the injection area and the Layne Well during this monitoring event, the data from 2009 was used to conservatively estimate residual mass in this area. The actual mass remaining is expected to be lower due to the effect of EVO injections in the source zone making the estimate of cleanup time using this mass conservative.

Attachment B
Calculation of TCE Mass In Soil
for BIOSCREEN Model Simulations
Shieldalloy Site
Newfield, New Jersey

ρ_b = bulk density of the soil, assumed to be 1.85 grams per cubic centimeter (g/cm3) or 52.4 kilograms per cubic foot (Kg/ft^3), which is considered reasonable for sands (Freeze and Cherry, 1979. Groundwater. Prentice-Hall, Englewood Cliffs, NJ).

The following table summarizes the TCE Mass Estimate for the Upper Zone.

Area of Interest	Length of Plume (feet)	Average Plume Width (feet)	Thickness of Impacted Zone (feet)	ρ_b (kg/ft^3)	Cs (mg/Kg)	M_{TCE} (kg)
Area between EVO Injections and Layne Well	923	348	40	52.4	0.0005	0.32
Area between Layne Well and SC-38I	930	205	40	52.4	0.0002	0.08
					Total =	0.40

Estimate of Soil Concentrations and Soil Mass in Lower Zone Near Farm Parcel for BIOSCREEN Simulations to Estimate Time to Achieve GWQS.

Based upon this information and groundwater analytical data for wells SC-1D, SC-3D(R), and SC-34D and width of the plume in October 2013, the estimated sorbed concentration of TCE on soil in the Lower Zone of the aquifer in the area defined by these three wells was calculated as follows:

Well	K_d	C_w	C_s	
	(ml/g)	(mg/ml)	(mg/g)	(mg/Kg)
SC-1D	0.069	0.0000297	0.0000020	0.0020
SC-3D(R)	0.069	0.0000234	0.0000016	0.0016
SC-34D	0.069	0.0000244	0.0000017	0.0017
			Average	0.0018
Between 1 and 10 µg/L contour	0.069	0.000006	0.0000004	0.0004
Between 1 and 10 µg/L contour	0.069	0.0000005	0.000000035	0.00003

The source area mass was estimated using a dry bulk density of 1.85 g/cm^3 (approximately 52.4 pounds per cubic foot soil), the distance from SC-3D(R) along a flowpath to the opposite side of North West Avenue (i.e., 1000 feet), the width of the plume , and the estimated saturated thickness of the lower zone beneath the Farm Parcel (approximately 55 feet), the mass of TCE sorbed within this block of soil was estimated to be:

Mass = Volume of soil in plume or estimated source area ($Length^3$) * dry bulk density of the soil (Soil Mass/$Length^3$) * estimated TCE concentration in soil (Mass TCE/Mass Soil)

For Center of Plume	= (1000 feet *1383 feet * 55 feet) * 52.4 kg/ft3 * 0.0018 mg/kg	=	7174451	mg
(between 10 ppb contours - see **Figure 2** provided with calculations of time to achieve GWQS)			**7**	kg
Between 1 and 10 ppb contours				
(See **Figure 2**)	= (1000 feet *150 feet * 55 feet * 2 sides) * 52.4 kg/ft3 * 0.0004 mg/kg	=	691680	mg
			0.7	Kg
Between 0 and 1 ppb contours	= (1000 feet *167 feet * 55 feet * 2 sides) * 52.4 kg/ft3 * 0.00003 mg/kg	=	51876	mg
(See **Figure 2**)			**0.05**	Kg
		total =	7918007	mg
			7.75 kg	~ 8 kg

ATTACHMENT C

BIOSCREEN CALIBRATION AND SIMULATION OF MNA OF TCE IN LOWER AQUIFER

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

Run 1 Cal parameters for Lower Aquifer, Predicted TCE Concentration in Lower Aquifer (Calibration)

Lower TCE Plume
Shield Alloy
Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
or 2. Calculate by filling in grey
0.02 cells below. (To restore formulas, hit button below).

Variable* → Data used directly in model.
20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	321.0	*(ft/yr)*
or		or	
Hydraulic Conductivity	*K*	3.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.0016	*(ft/ft)*
Porosity	*n*	0.2	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	21.8	*(ft)*
Transverse Dispersivity*	*alpha y*	2.2	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		or	
Estimated Plume Length	*Lp*	767	*(ft)*

3. ADSORPTION

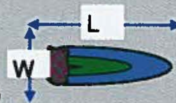
Retardation Factor*	*R*	1.1	*(-)*
or		or	
Soil Bulk Density	*rho*	1.85	*(kg/l)*
Partition Coefficient	*Koc*	126	*(L/kg)*
FractionOrganicCarbon	*foc*	1.8E-4	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	9.0E-2	*(per yr)*
or		or	
Solute Half-Life	*t-half*	7.70	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	767	*(ft)*
Modeled Area Width*	2000	*(ft)*
Simulation Time*	4	*(yr)*



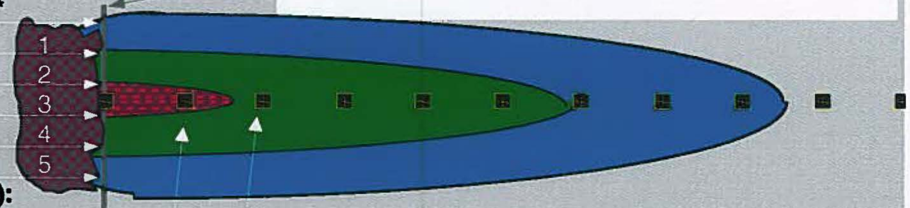
6. SOURCE DATA

Source Thickness in Sat.Zone* 10 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
167	0.0005
150	0.006
1383	0.042
150	0.006
167	0.0005



View of Plume Looking Down

Source Halflife (see Help):

5	5	*(yr)*
Inst. React.	1st Order	
Soluble Mass	8	*(Kg)*

In Source Soil porewater

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	.024										.027
Dist. from Source (ft)	0	77	153	230	307	384	460	537	614	690	767

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | RUN ARRAY | Help | Recalculate This

View Output | View Output | Paste Example Dataset

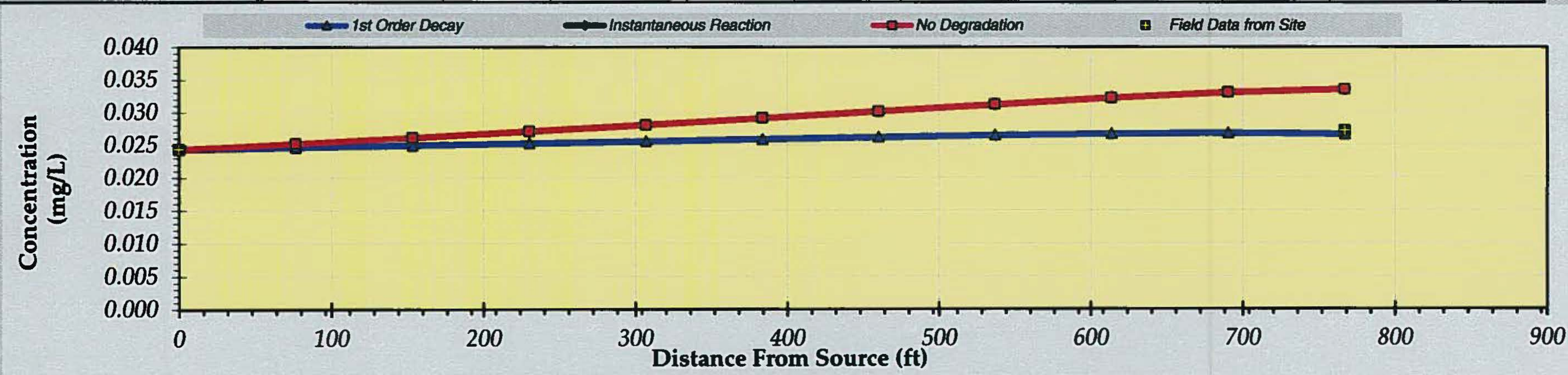
Restore Formulas for Vs,

Calibration to CONCENTRATIONS at SC-1D and SC-34D

CAL RUN 1 INPUT

LOWER PLUME TCE CONCENTRATION ALONG PLUME CENTERLINE SINCE GW EXTRACTION CEASED (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	77	153	230	307	384	460	537	614	690	767
No Degradation	0.024	0.025	0.026	0.027	0.028	0.029	0.030	0.031	0.032	0.033	0.034
1st Order Decay	0.024	0.025	0.025	0.025	0.026	0.026	0.026	0.026	0.027	0.027	0.027
Inst. Reaction	0.024	0.025	0.026	0.027	0.028	0.029	0.030	0.031	0.032	0.033	0.034
Field Data from Site	0.024										0.027



Calculate Animation

estep

estep

Time:

4 Years

Return to

Recalculate This

RUN 1 INPUT CALIBRATION OF TCE CONCENTRATIONS IN LOWER PLUME SINCE PUMPING CEASED (mg/L at Z=0)

Transverse Distance (ft)	Distance from Source (ft) 0	77	153	230	307	384	460	537	614	690	767
1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
500	0.024	0.025	0.025	0.025	0.026	0.026	0.026	0.026	0.027	0.027	0.027
0	0.024	0.025	0.025	0.025	0.026	0.026	0.026	0.026	0.027	0.027	0.027
-500	0.024	0.025	0.025	0.025	0.026	0.026	0.026	0.026	0.027	0.027	0.027
-1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	3.0E+3	1.8E+3	1.9E+3	1.9E+3	1.9E+3	1.9E+3	2.0E+3	2.0E+3	2.0E+3	2.0E+3	2.0E+3

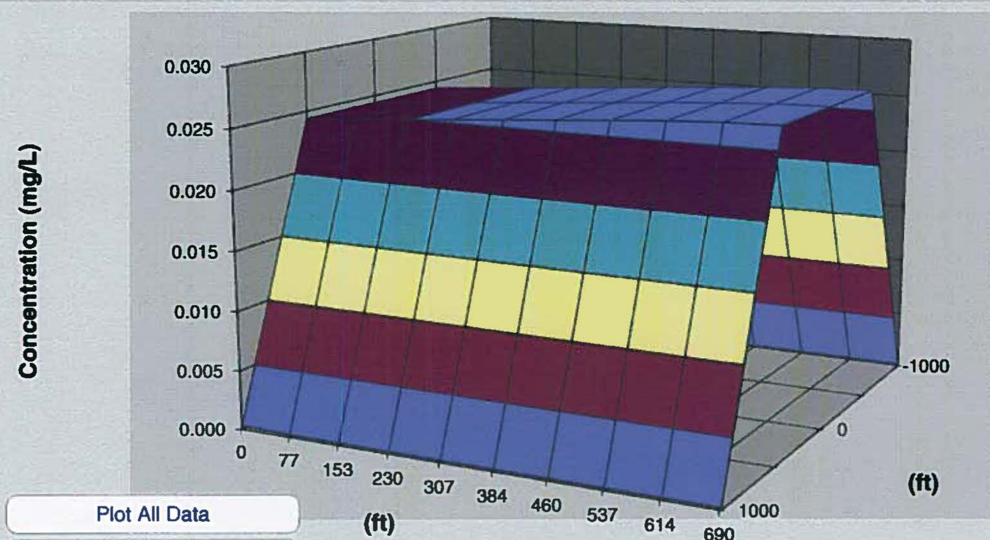
Time: **4 Years** Target Level: **0.001** mg/L Displayed Model: **1st Order Decay**

Model to Display:

No Degradation

1st Order Decay

Instantaneous



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	3.4	*(Kg)*
- Actual Plume Mass	2.7	*(Kg)*
= Plume Mass Removed by Biodeg	**0.7**	*(Kg)* (20 %)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	8.0	*(Kg)*
Contam. Mass in Source Now (t=4Years)	4.6	*(Kg)*
Current Volume of Groundwater in Plume	58.1	*(ac-ft)*
Flowrate of Water Through Source Zone	29.727	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

Run 1 Cal parameters, Predicted TCE Concentration in Lower Aquifer Source at Farm (time to 1 ppb in plume)

Run Name: *Lower TCE Plume* / *Shield Alloy*

Data Input Instructions:

115 — 1. Enter value directly....or
or — 2. Calculate by filling in grey
0.02 — cells below. (To restore formulas, hit button below).

Variable* → Data used directly in model.
20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	321.0	(ft/yr)
or		or	
Hydraulic Conductivity	K	3.9E-02	(cm/sec)
Hydraulic Gradient	i	0.0016	(ft/ft)
Porosity	n	0.2	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	55.1	(ft)
Transverse Dispersivity*	alpha y	5.5	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or		or	
Estimated Plume Length	Lp	9800	(ft)

3. ADSORPTION

Retardation Factor*	R	1.1	(-)
or		or	
Soil Bulk Density	rho	1.85	(kg/l)
Partition Coefficient	Koc	126	(L/kg)
FractionOrganicCarbon	foc	1.8E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	9.0E-2	(per yr)
or		or	
Solute Half-Life	t-half	7.70	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	0	(mg/L)
Delta Nitrate*	NO3	0	(mg/L)
Observed Ferrous Iron*	Fe2+	0	(mg/L)
Delta Sulfate*	SO4	0	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	11000	(ft)
Modeled Area Width*	2000	(ft)
Simulation Time*	35	(yr)

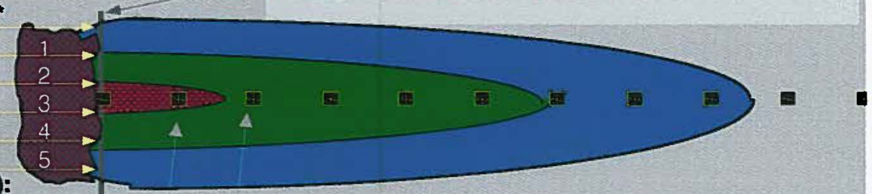
6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
167	0.0005
150	0.006
1383	0.042
150	0.006
167	0.0005



View of Plume Looking Down

Source Halflife (see Help):

Inst. React.	1st Order	
5	5	(yr)

Soluble Mass 8 (Kg)

In Source Soil porewater

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	1100	2200	3300	4400	5500	6600	7700	8800	9900	####

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — View Output

RUN ARRAY — View Output

Help | Recalculate This

Paste Example Dataset

Restore Formulas for Vs,

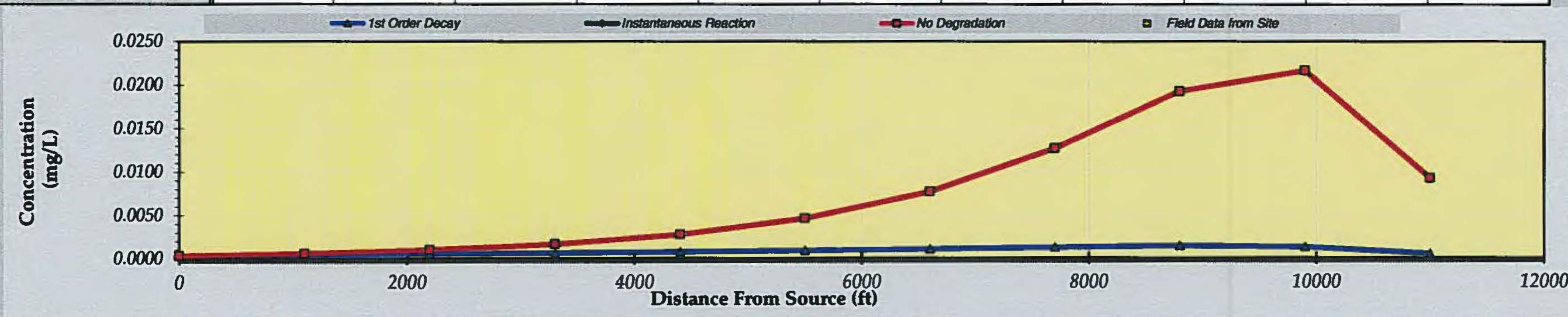
Simulated Time to achieve TCE CONCENTRATION <1 ppb GWQS Throughout LOWER PLUME

CAL RUN 1 INPUT

LOWER PLUME - TIME TO ATTAIN 1 PPB TCE CONCENTRATION IN ENTIRE PLUME ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	1100	2200	3300	4400	5500	6600	7700	8800	9900	11000
No Degradation	0.000	0.001	0.001	0.002	0.003	0.005	0.008	0.013	0.019	0.022	0.009
1st Order Decay	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000
Inst. Reaction	0.000	0.001	0.001	0.002	0.003	0.005	0.008	0.013	0.019	0.022	0.009
Field Data from Site											



Calculate Animation

tep

tep

Time:

35 Years

Return to

Recalculate This Sheet

Transverse Distance (ft) RUN 1 INPUT TIME TO ACHIEVE TCE CONCENTRATIONS IN LOWER PLUME LESS THAN 1 PPB IN ENTIRE PLUME (mg/L at Z=0)

Distance from Source (ft)

	0	1100	2200	3300	4400	5500	6600	7700	8800	9900	11000
1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
500	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000
0	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000
-500	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000
-1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	3.0E+3	3.1E+1	3.7E+1	4.4E+1	5.2E+1	6.2E+1	7.4E+1	8.9E+1	1.0E+2	9.3E+1	3.6E+1

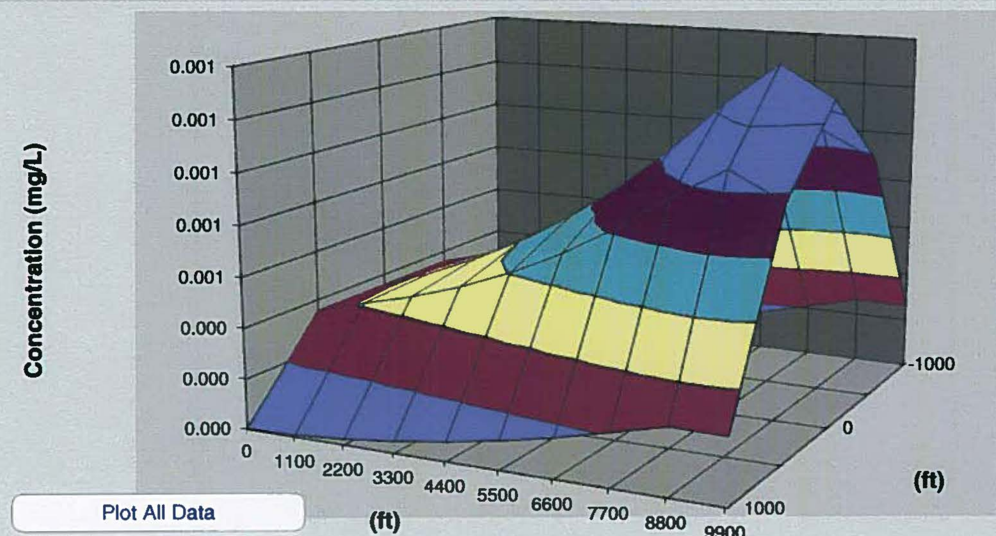
Time: **35 Years** Target Level: **0.001** mg/L Displayed Model: **1st Order Decay**

Model to Display:

No Degradation

1st Order Decay

Instantaneous



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	7.9	*(Kg)*
- Actual Plume Mass	0.8	*(Kg)*
= Plume Mass Removed by Biodeg	7.2	*(Kg)* (90 %)

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	8.0	*(Kg)*
Contam. Mass in Source Now (t=35Years)	0.1	*(Kg)*
Current Volume of Groundwater in Plume	0.0	*(ac-ft)*
Flowrate of Water Through Source Zone	29.727	*(ac-ft/yr)*

Mass HELP

Recalculate

ATTACHMENT D

BULK ATTENUATION FACTOR CALCULATIONS FOR TCE IN UPPER ZONE

Attachment D
Estimate of Bulk Attenuation Rate
Factors for TCE in Upper Zone
Shieldalloy Metallurgical Corporation
Newfields, New Jersey

Calculations by: JSH
Checked by: NR

Problem Statement:

Estimate a bulk attenuation rate for TCE in the Upper Zone of the Aquifer to model the attenuation of residual TCE remaining in groundwater at the Facility.

Approach:

Use the method described in "Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies" (EPA, 2002).

1. Plot natural log of concentration versus distance along a flowpath.
2. Perform regression analysis of the data to calculate the slope of the natural log of concentration versus distance (see plots).
3. Multiply the slope calculated from the regression analysis by the contaminant transport velocity to obtain the bulk attenuation factor (rate constant, λ).
4. Calculate the half-life of dissolved TCE = $0.693/\lambda$.

Data from wells SC-3S and SC-1S were selected to estimate the bulk attenuation rate constant for the following reasons:

1. There are no shallow wells located along a flow path containing TCE at the facility outside of the influence of the pumping wells.
2. Wells SC-1S and SC-3S are screened at the same interval and depth in the Upper Zone of the aquifer that TCE impacts are observed at the Facility, and are both located along a flowpath as flow is dominantly horizontal between the wells.
3. Both wells are located downgradient of historical pumping influences and therefore reflect natural attenuation processes in the aquifer.

Although ideal, three wells were not available along the same flowpath to estimate 'the bulk attenuation rate. However, regression analyses performed for several rounds of data indicate that the reduction in TCE concentration is generally consistent and was thus judged to be representative of bulk attenuation rates for the Upper Zone of the aquifer. It is assumed that the range of bulk attenuation rates calculated for these wells is representative of the area of the residual TCE plume in the upper aquifer at the southwest corner of the SMC at the facility based upon similar hydrogeologic conditions.

Steps 1 and 2: Plot Natural Log of Concentration versus distance along flowpath.

Sample Event	Well Location	Distance Along Flowpath, D (feet)	TCE Concentration,C (µg/L)	Slope of C vs. D (per foot)
Oct-06	SC-3S	1	1.90	0.003
	SC-1S	359	0.64	
Jan-07	SC-3S	1	1.40	0.002
	SC-1S	359	0.74	
Apr-07	SC-3S	1	1.60	0.004
	SC-1S	359	0.44	
Jul-07	SC-3S	1	1.80	0.003
	SC-1S	359	0.53	
Oct-07	SC-3S	1	1.90	0.004
	SC-1S	359	0.47	
Jan-08	SC-3S	1	1.80	0.003
	SC-1S	359	0.66	

Attachment D
Estimate of Bulk Attenuation Rate
Factors for TCE in Upper Zone
Shieldalloy Metallurgical Corporation
Newfields, New Jersey

Sample Event	Well Location	Distance Along Flowpath, D (feet)	TCE Concentration,C (µg/L)	Slope of C vs. D (per foot)
Apr-08	SC-3S	1	2.60	0.005
	SC-1S	359	0.48	
Jul-08	SC-3S	1	2.10	0.005
	SC-1S	359	0.33	
Oct-08	SC-3S	1	1.90	0.003
	SC-1S	359	0.63	
Jan-09	SC-3S	1	1.80	0.003
	SC-1S	359	0.54	
Apr-12	SC-3S	1	2.90	0.006
	SC-1S	359	0.37	

Median	0.003
Geomean	0.004

Steps 3 and 4: Calculation of Bulk Attenuation Rate and Half-Life

The range of groundwater velocity in the Upper Zone of the aquifer in the area of the Facility was calculated using transmissivities calculated from data obtained during a pumping test performed on the Layne Well using the the Theis, Hantush, and/or Boulton Method, an ambient groundwater hydraulic gradient of 0.0016 estimated from water level data collected outside of the area of pumping influence during April 2012, and a range of effective porosity typical of medium to coarse sand as described by Walton (1991) in Principles of Groundwater Engineering Lewis Publishers, Boca Raton Florida. Transmissivity resul for the Layne Well pumping test are presented in Raviv, 1990. *Summary of Geohydrologic Information* Collected Since January 1988, Shieldalloy Metallurgical Corporation, Newfields, New Jersey. The transport velocity for TCE was estimated by dividing the calculated groundwater seepage velocity by a retardation factor of 1.1 (refer to Attachment A of remedial timeframe calculations).

The groundwater seepage velocity was calculated using the following equation:

$$V_{gw} = [(T/b) * i]/n_e$$

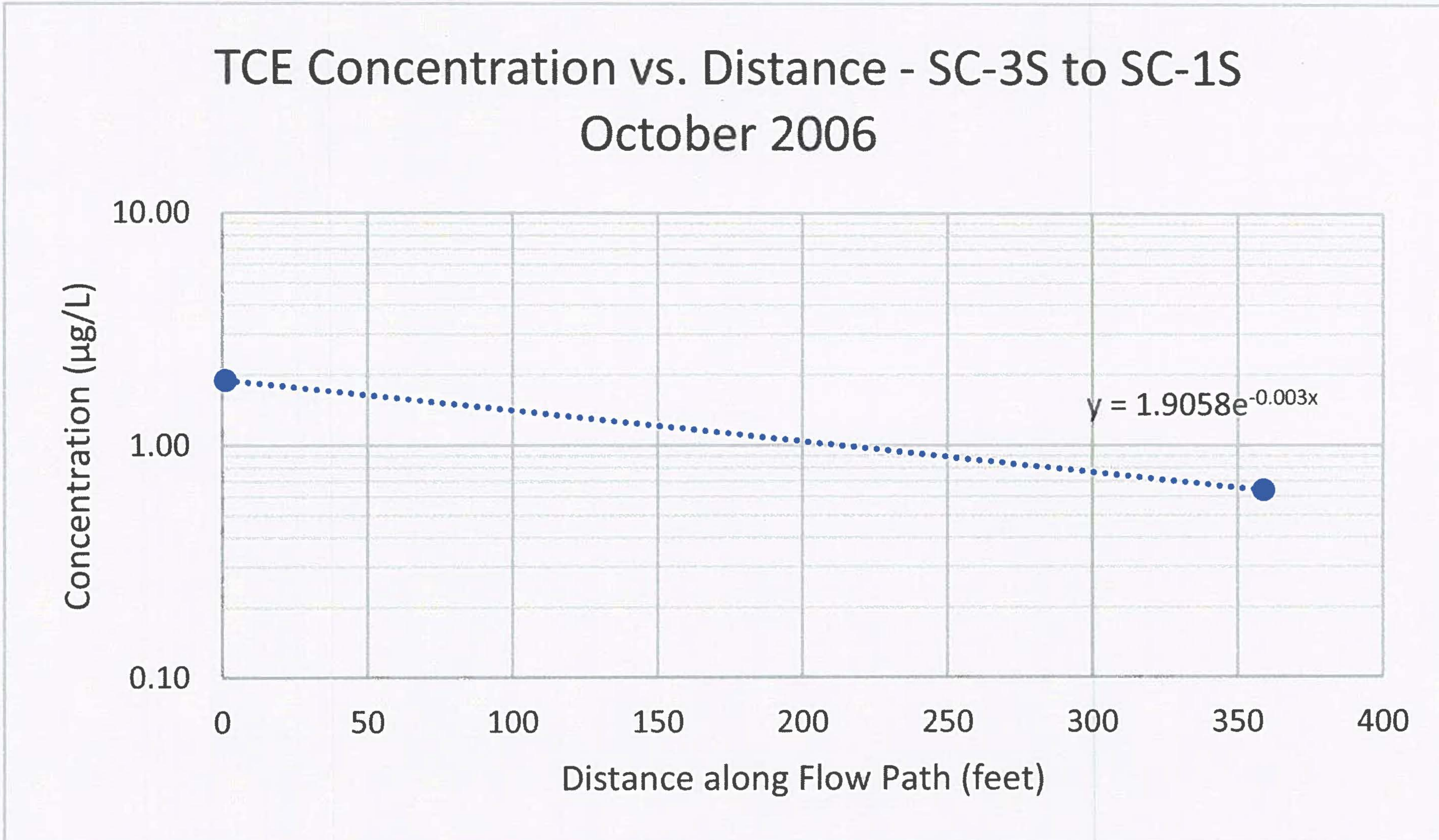
Where: T = transmissivity (ft^2/day)
b = saturated thickness of the upper zone (feet) - approximately 80 feet beneath the facility;
i = horizontal hydraulic gradient (dimensionless); and
n_e = effective porosity (dimensionless).

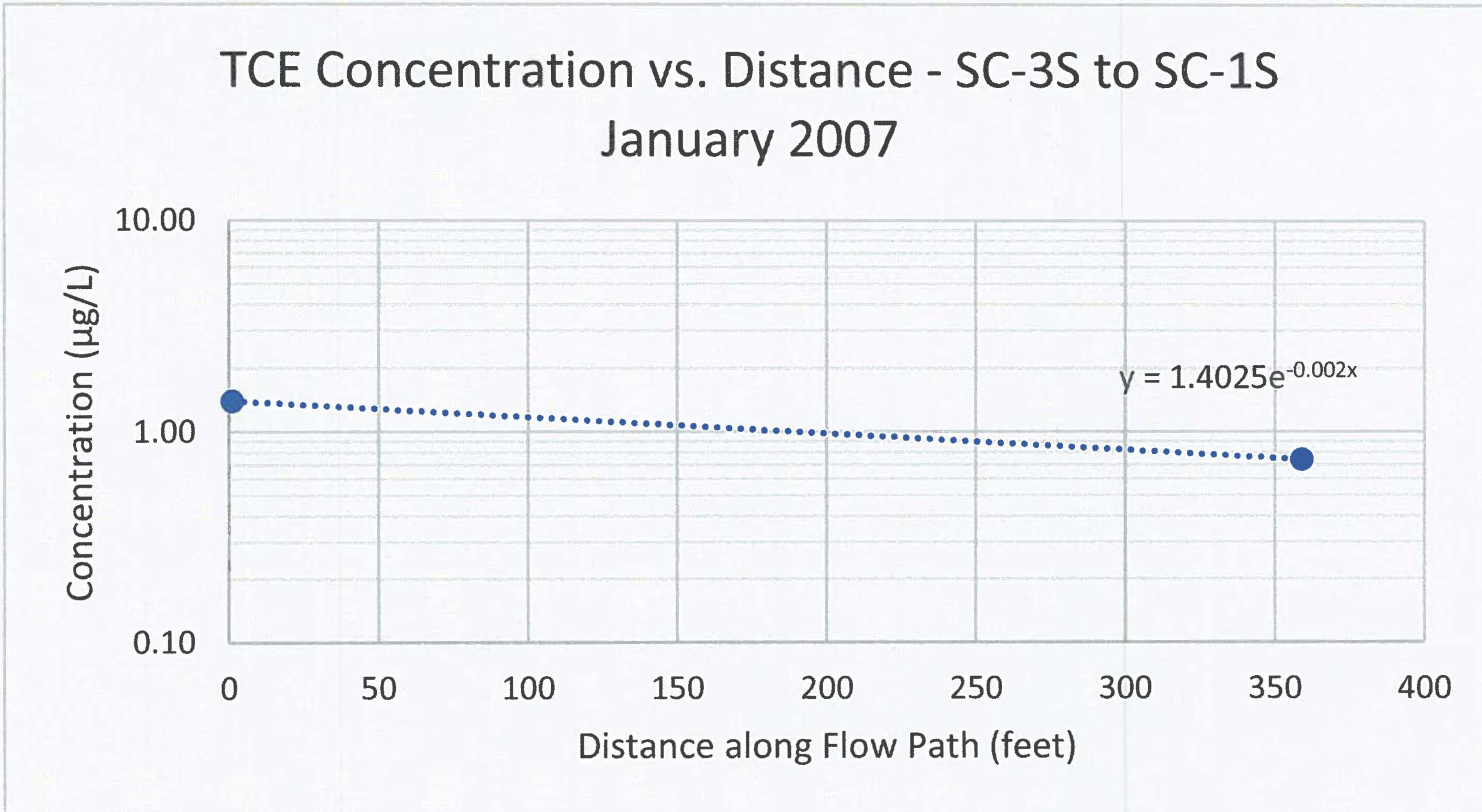
	T (ft^2/day)	b (feet)	i	n_e	V_{gw} (ft/day)	V_{gw} (ft/yr)	R	V_{tce} (ft/day)
Lower End	3329	80	0.0016	0.35	0.19	69	1.1	63
Upper End	10642	80	0.0016	0.2	1.06	388	1.1	353

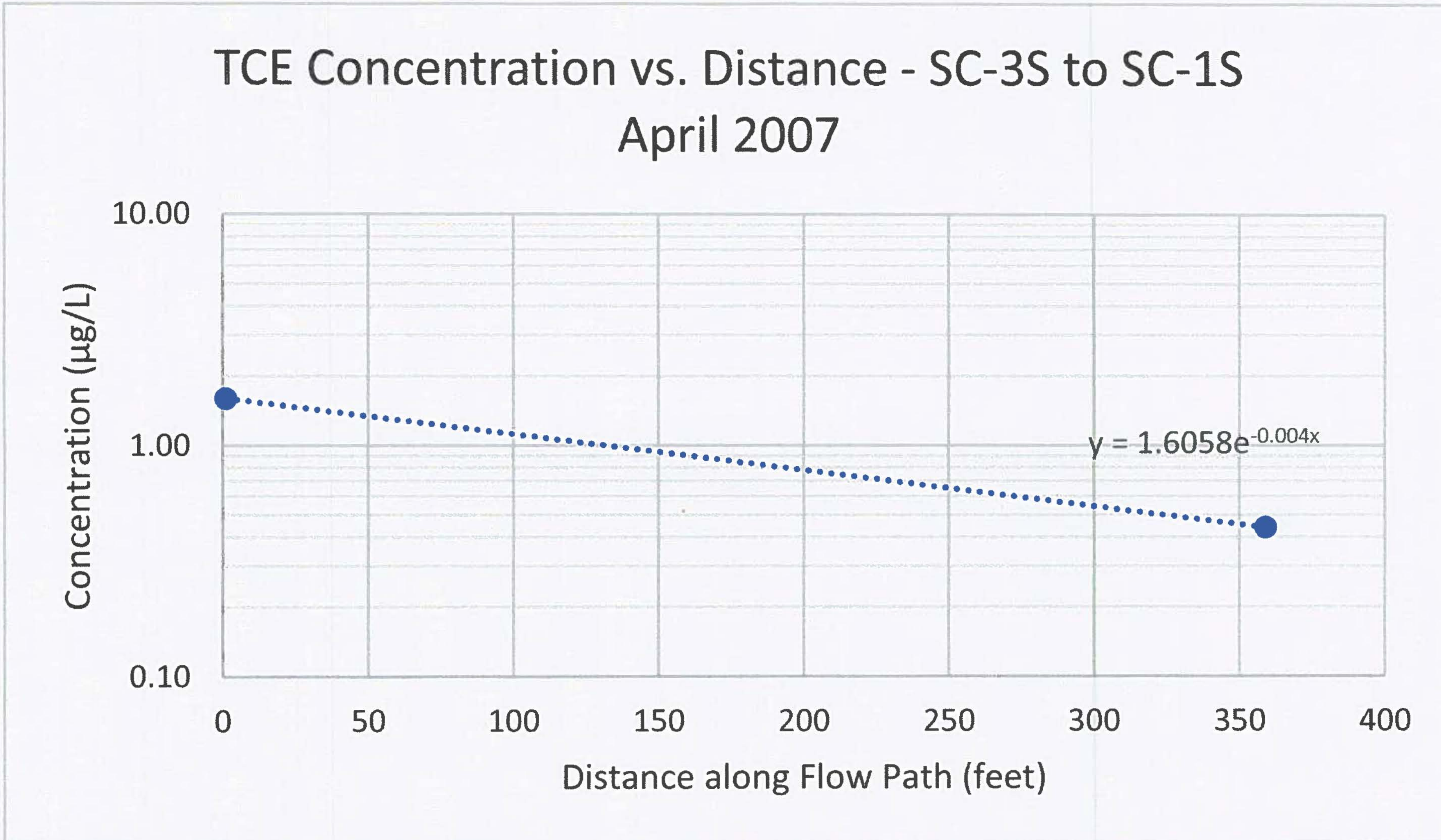
Attachment D
Estimate of Bulk Attenuation Rate
Factors for TCE in Upper Zone
Shieldalloy Metallurgical Corporation
Newfields, New Jersey

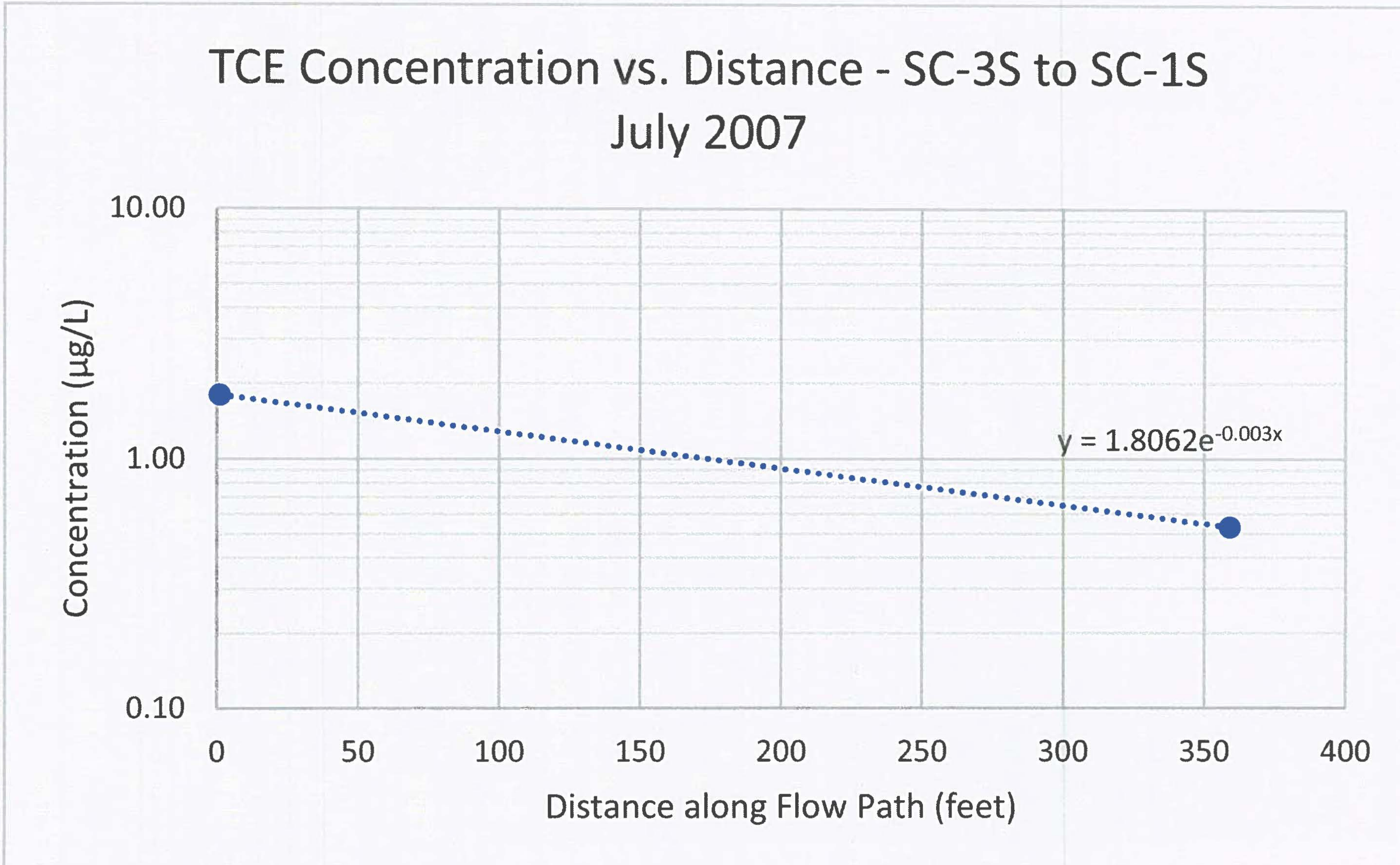
Using these data, the range of bulk attenuation factors for TCE in groundwater in the Upper Zone of the aquifer was estimated as follows:

	TCE Transport Velocity (feet/year)	Slope of Concentration vs. Distance (per foot)	Bulk Attenuation Rate Constant (per year)	Half Life (years)	Reported TCE half-life (*) in groundwater
Lower End	63	0.003	0.2	3.7	0.3 - 4.5 years
Upper End	290	0.004	1.2	0.6	
		Geomean	0.47	1.48	

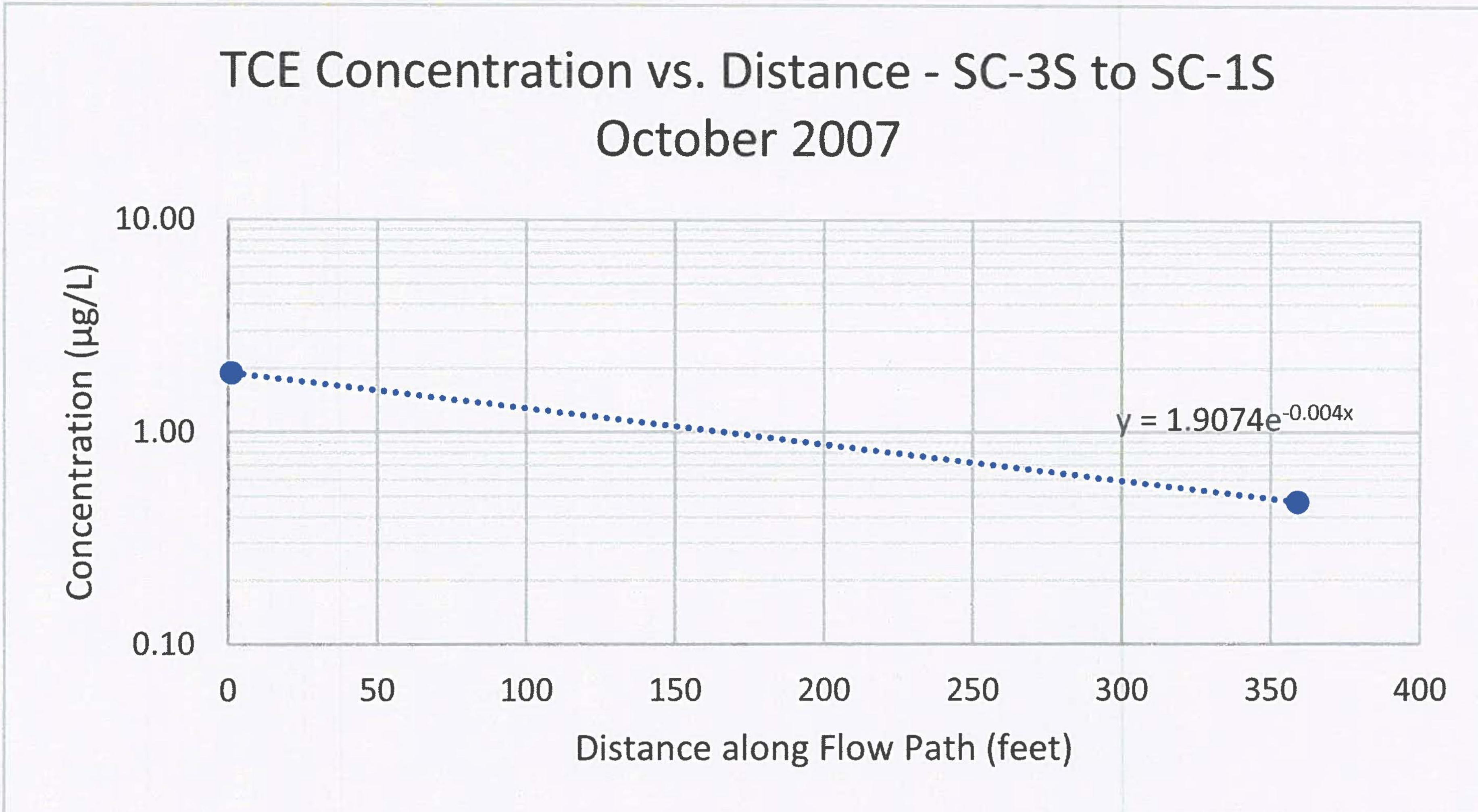

TCE Concentration vs. Distance - SC-3S to SC-1S
October 2006
10.00
1.00
0.10
Concentration (µg/L)
y = 1.9058e-0.003x
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)


TCE Concentration vs. Distance - SC-3S to SC-1S
January 2007
y = 1.4025e^-0.002x
10.00
1.00
0.10
Concentration (µg/L)
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)

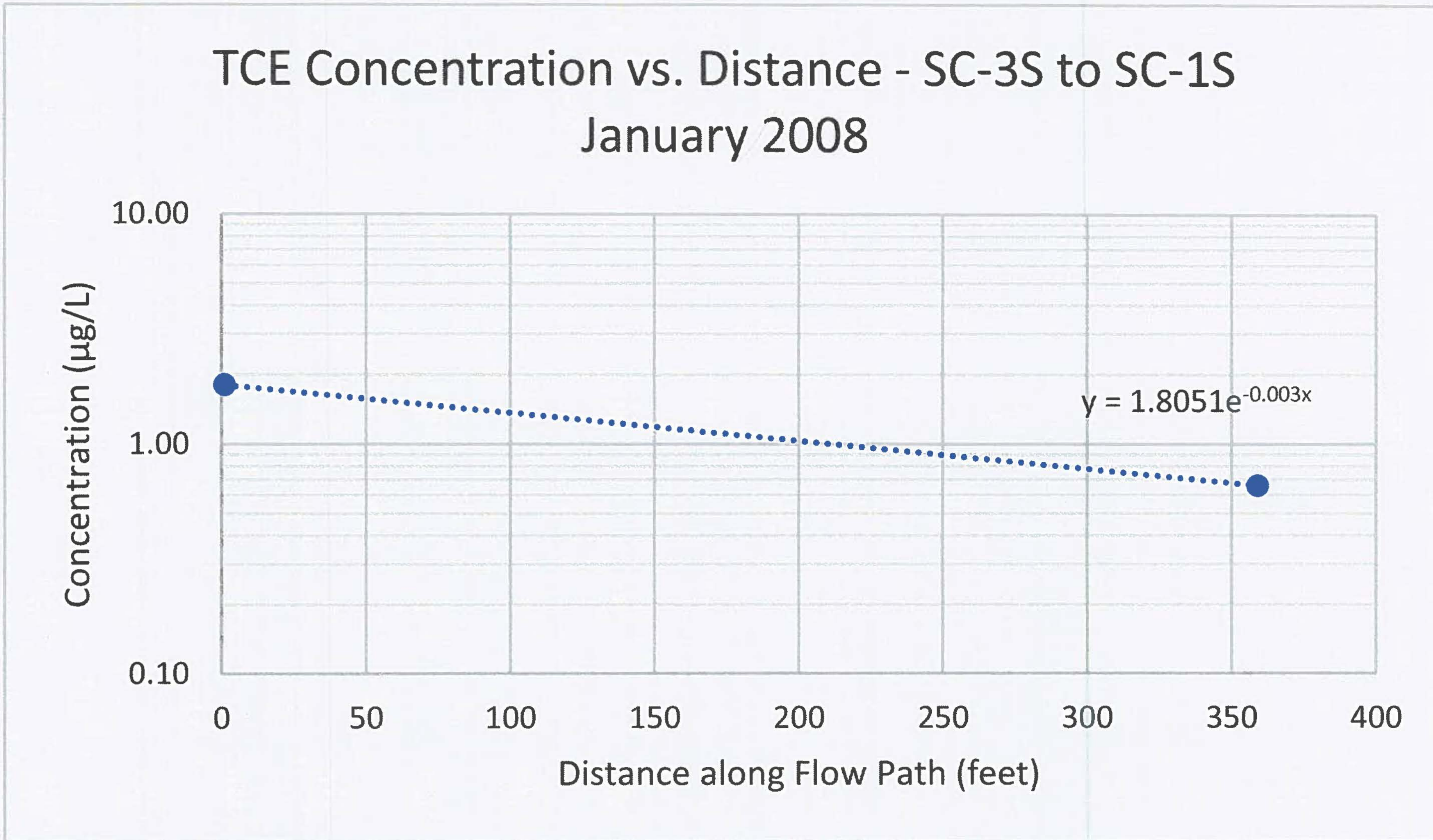

TCE Concentration vs. Distance - SC-3S to SC-1S
April 2007
10.00
1.00
0.10
Concentration (µg/L)
y = 1.6058e-0.004x
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)

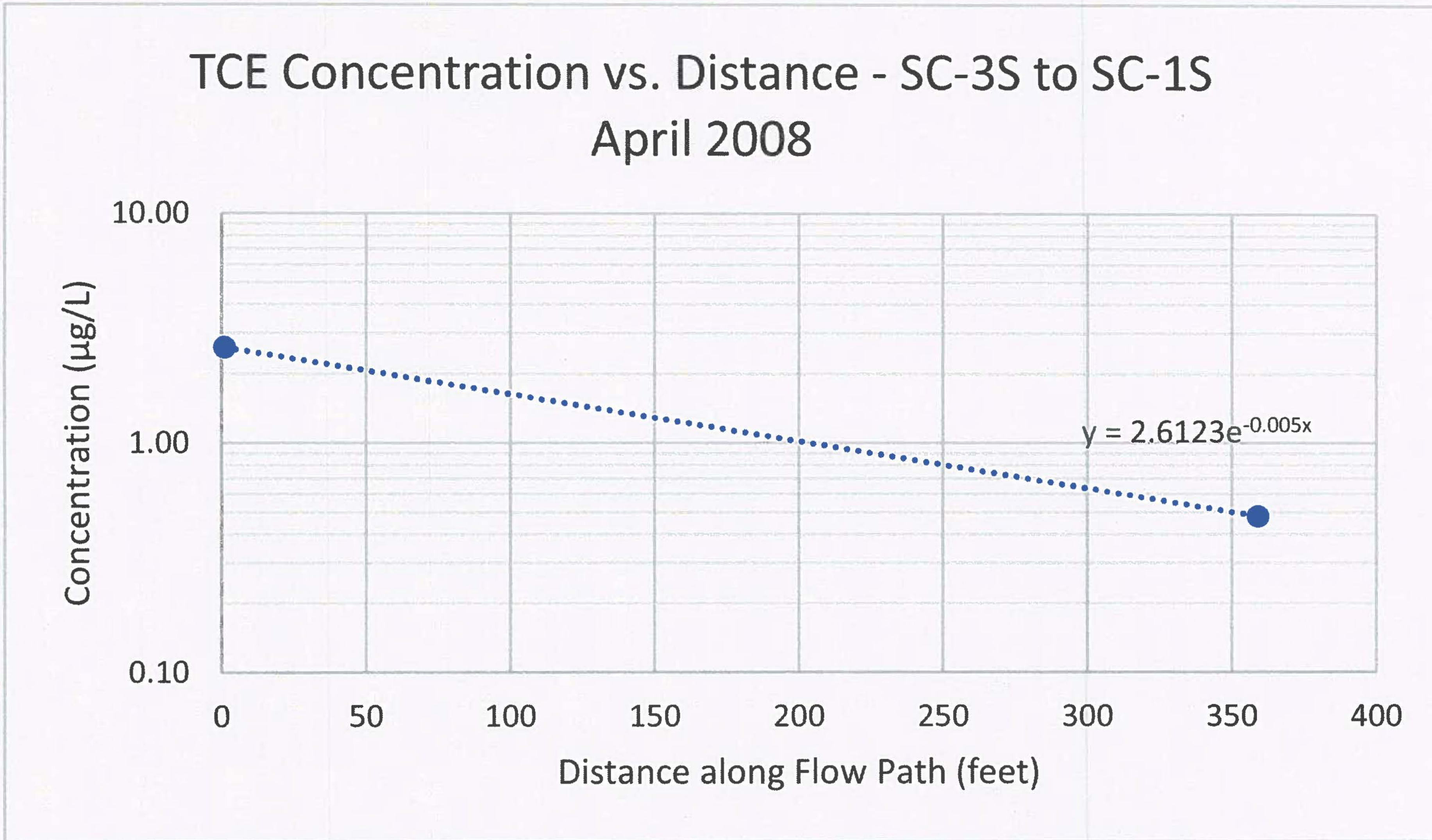


TCE Concentration vs. Distance - SC-3S to SC-1S
July 2007
10.00
1.00
0.10
Concentration (µg/L)
y = 1.8062e^-0.003x
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)

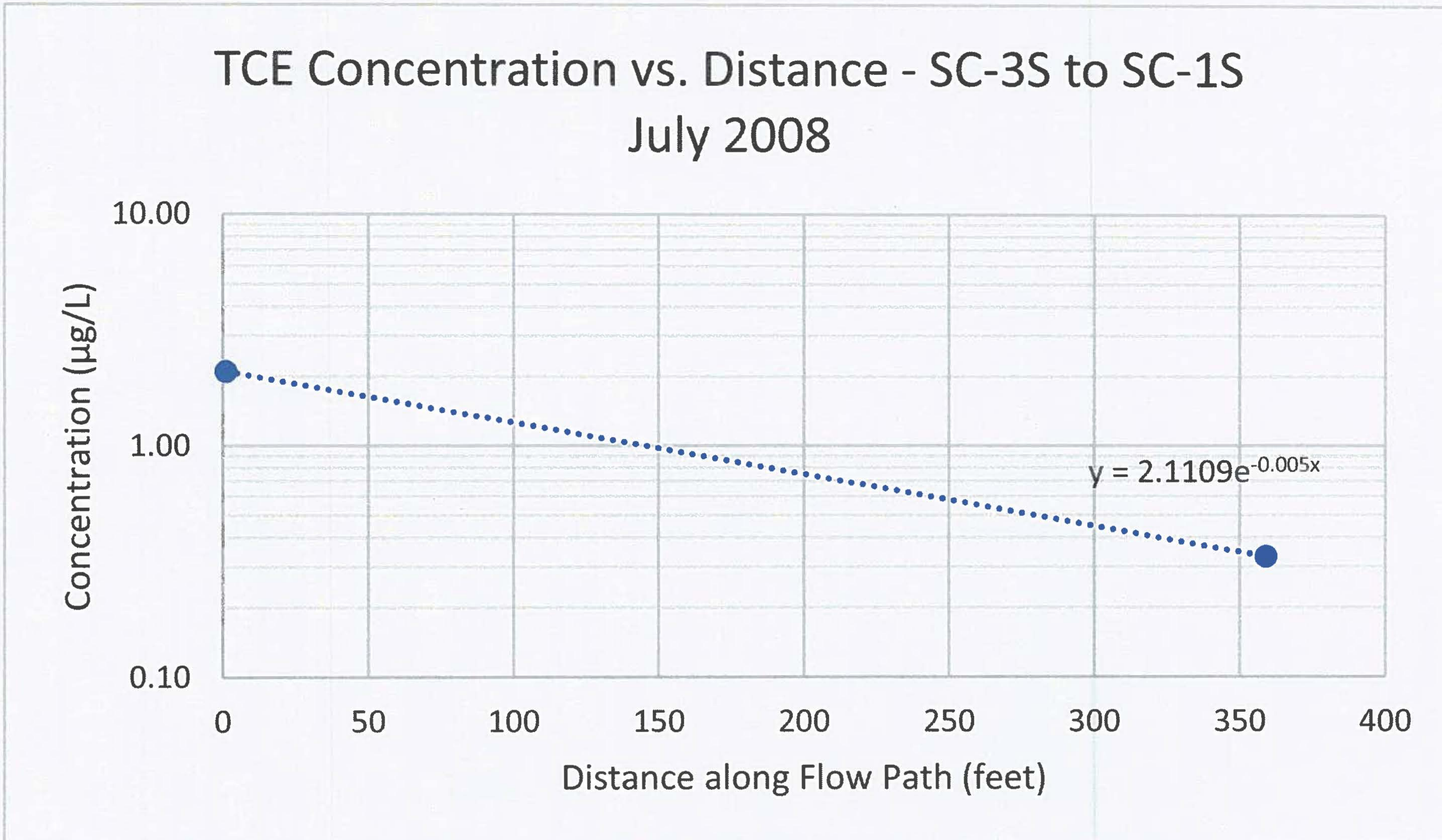


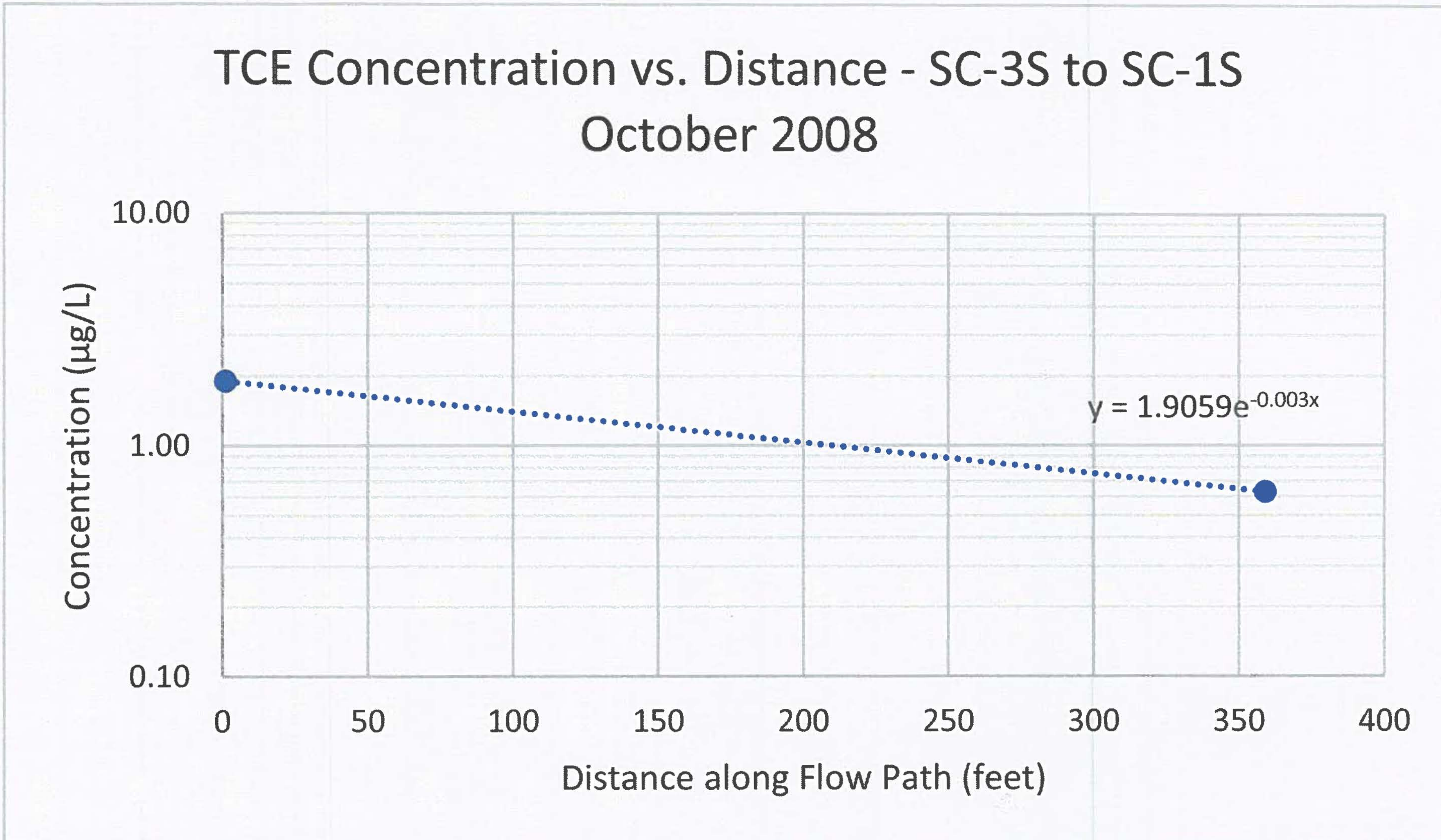
TCE Concentration vs. Distance - SC-3S to SC-1S
October 2007
10.00
1.00
0.10
Concentration (µg/L)
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)
y = 1.9074e^-0.004x

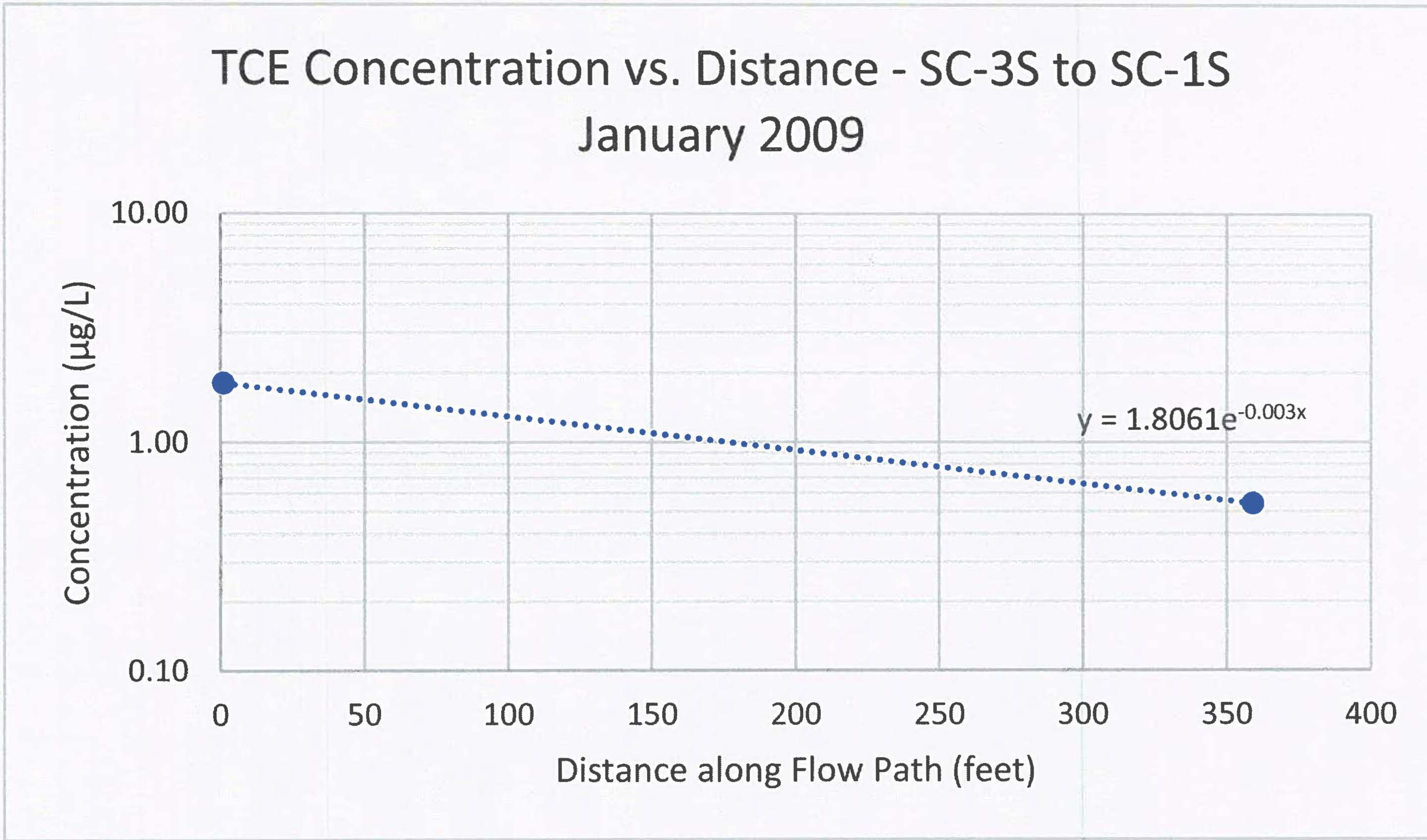

TCE Concentration vs. Distance - SC-3S to SC-1S
January 2008
10.00
1.00
0.10
Concentration (µg/L)
y = 1.8051e^-0.003x
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)



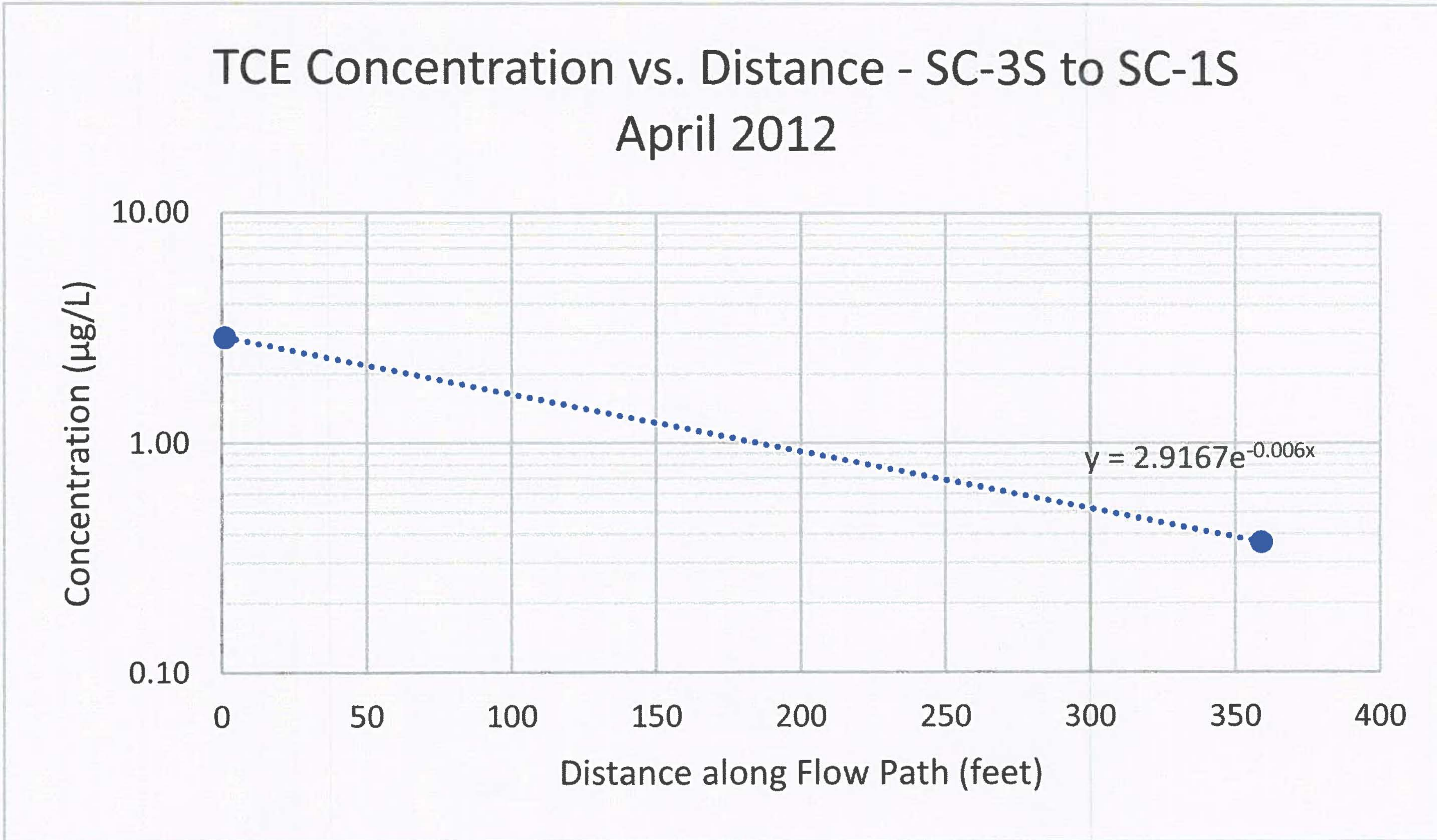
TCE Concentration vs. Distance - SC-3S to SC-1S
April 2008
10.00
1.00
0.10
Concentration (µg/L)
y = 2.6123e^-0.005x
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)


TCE Concentration vs. Distance - SC-3S to SC-1S
July 2008
Concentration (µg/L)
10.00
1.00
0.10
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)
y = 2.1109e-0.005x


TCE Concentration vs. Distance - SC-3S to SC-1S
October 2008
10.00
1.00
0.10
Concentration (µg/L)
y = 1.9059e^-0.003x
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)



TCE Concentration vs. Distance - SC-3S to SC-1S
January 2009
10.00
1.00
0.10
Concentration (µg/L)
y = 1.8061e^-0.003x
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)



TCE Concentration vs. Distance - SC-3S to SC-1S
April 2012
10.00
1.00
0.10
Concentration (µg/L)
y = 2.9167e-0.006x
0
50
100
150
200
250
300
350
400
Distance along Flow Path (feet)

ATTACHMENT E

BIOSCREEN SIMULATIONS FOR MNA OF RESIDUAL TCE IN UPPER ZONE

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

Run B Simulation of TCE Attenuation in Upper Plume Zone

Upper TCE Plume post source remedy SMC (Run B)

Run Name

Data Input Instructions:

115	1. Enter value directly....or
or	2. Calculate by filling in grey cells below. (To restore formulas, hit button below).
0.02	
Variable*	Data used directly in model.
20	Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	146.0	(ft/yr)
or		or	
Hydraulic Conductivity	K	2.6E-02	(cm/sec)
Hydraulic Gradient	i	0.0016	(ft/ft)
Porosity	n	0.3	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.7	(ft)
Transverse Dispersivity*	alpha y	2.4	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or		or	
Estimated Plume Length	Lp	930	(ft)

3. ADSORPTION

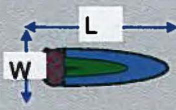
Retardation Factor*	R	1.1	(-)
or		or	
Soil Bulk Density	rho	1.85	(kg/l)
Partition Coefficient	Koc	126	(L/kg)
FractionOrganicCarbon	foc	1.5E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	2.0E-1	(per yr)
or		or	
Solute Half-Life	t-half	3.50	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	0	(mg/L)
Delta Nitrate*	NO3	0	(mg/L)
Observed Ferrous Iron*	Fe2+	0	(mg/L)
Delta Sulfate*	SO4	0	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	2500	(ft)
Modeled Area Width*	2000	(ft)
Simulation Time*	40	(yr)



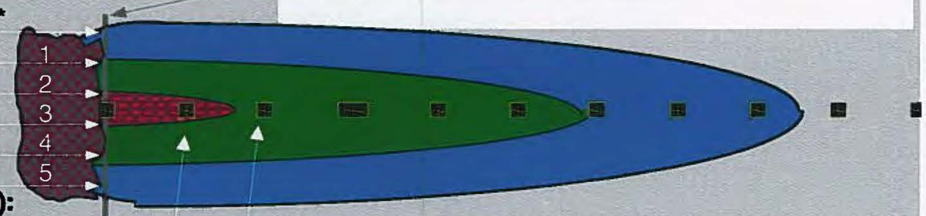
6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
42	0.003
42	0.0075
84	0.016
42	0.0075
42	0.003

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths



View of Plume Looking Down

Source Halflife (see Help):

10	10	(yr)
Inst. React.	1st Order	
Soluble Mass	0.4	(Kg)

In Source Soil porewater

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	250	500	750	1000	1250	1500	1750	2000	2250	2500

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — View Output

RUN ARRAY — View Output

Help

Recalculate This

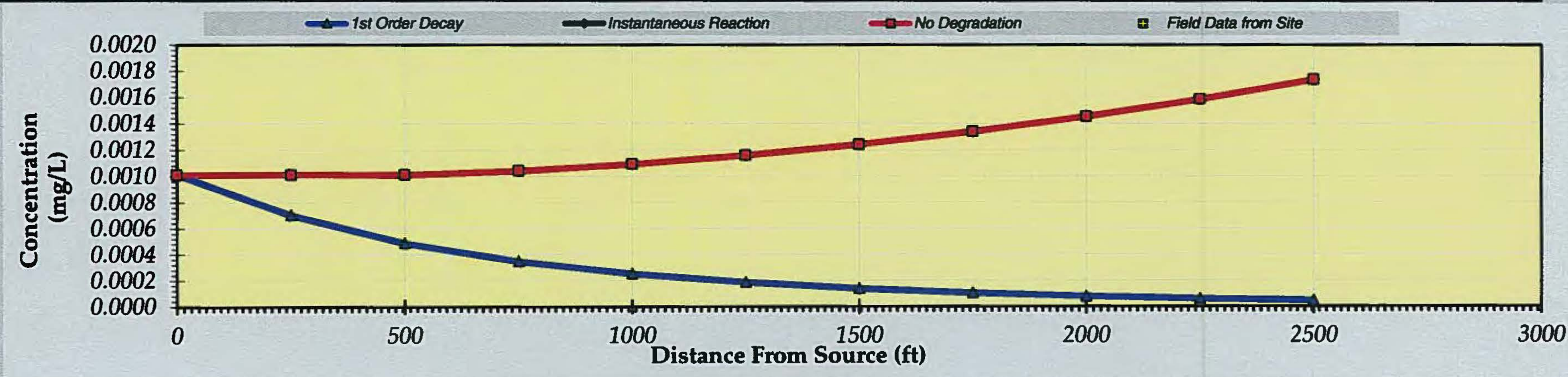
Paste Example Dataset

Restore Formulas for Vs,

CAL RUN B INPUT

ESTIMATE OF TIME TO REDUCE RESIDUAL TCE BELOW NJDEP GWQS IN UPPER AQUIFER (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	250	500	750	1000	1250	1500	1750	2000	2250	2500
No Degradation	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002
1st Order Decay	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002
Field Data from Site											



Calculate Animation

estep

estep

Time:

40 Years

Return to

Recalculate This

RUN B INPUT PREDICTED TIME TO REDUCE RESIDUAL TCE BELOW NJDEP GWQS (mg/L at Z=0)

Transverse Distance (ft) / ***Distance from Source (ft)***

	0	250	500	750	1000	1250	1500	1750	2000	2250	2500
1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	7.6E+1	1.2E+1	8.3E+0	5.9E+0	4.3E+0	3.2E+0	2.4E+0	1.8E+0	1.3E+0	1.0E+0	7.6E-1

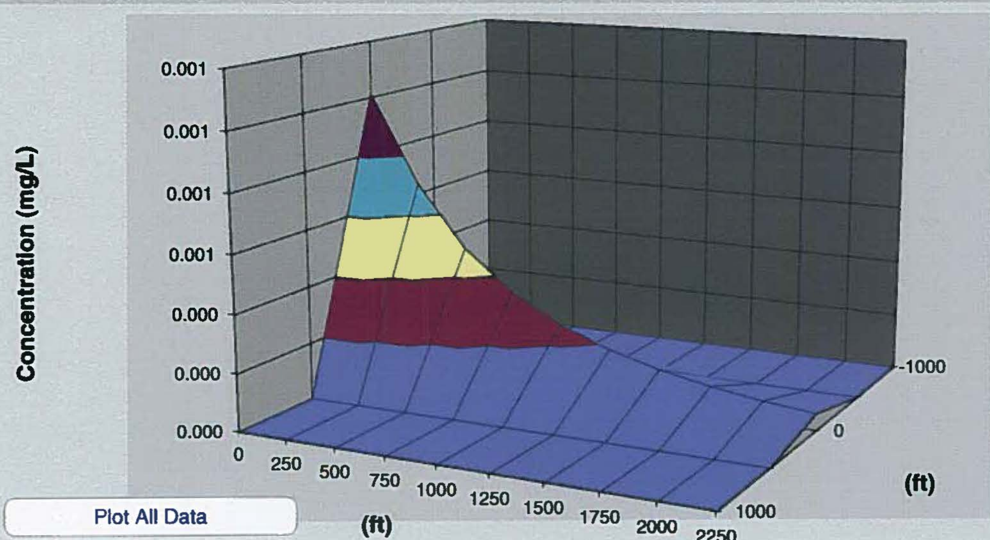
Time: **40 Years** Target Level: **0.001** mg/L Displayed Model: **1st Order Decay**

Model to Display:

No Degradation

1st Order Decay

Instantaneous



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	Can't Calc.	*(Kg)*
- Actual Plume Mass	Can't Calc.	*(Kg)*
= Plume Mass Removed by Biodeg	-	*(Kg)*

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	0.4	*(Kg)*
Contam. Mass in Source Now (t=40Years)	0.0	*(Kg)*
Current Volume of Groundwater in Plume	Can't Calc.	*(ac-ft)*
Flowrate of Water Through Source Zone	Can't Calc.	*(ac-ft/yr)*

Mass HELP

Recalculate

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

Run C Simulation of TCE Attenuation in Upper Plume Zone

Upper TCE Plume
post source remedy
SMC (run C)
Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
or 2. Calculate by filling in grey
0.02 cells below. (To restore formulas, hit button below).
Variable* → Data used directly in model.
20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	310.0	(ft/yr)
or		or	
Hydraulic Conductivity	K	4.7E-02	(cm/sec)
Hydraulic Gradient	i	0.0016	(ft/ft)
Porosity	n	0.25	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.7	(ft)
Transverse Dispersivity*	alpha y	2.4	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or		or	
Estimated Plume Length	Lp	930	(ft)

3. ADSORPTION

Retardation Factor*	R	1.1	(-)
or		or	
Soil Bulk Density	rho	1.85	(kg/l)
Partition Coefficient	Koc	126	(L/kg)
FractionOrganicCarbon	foc	1.5E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	2.0E-1	(per yr)
or		or	
Solute Half-Life	t-half	3.50	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	0	(mg/L)
Delta Nitrate*	NO3	0	(mg/L)
Observed Ferrous Iron*	Fe2+	0	(mg/L)
Delta Sulfate*	SO4	0	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	2500	(ft)
Modeled Area Width*	2000	(ft)
Simulation Time*	30	(yr)

L W

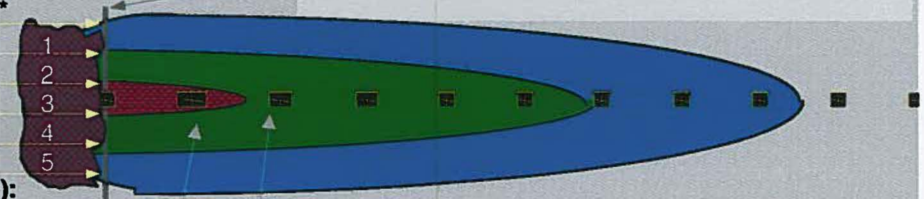
6. SOURCE DATA

Source Thickness in Sat.Zone* 7.5 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths

Source Zones:

Width* (ft)	Conc. (mg/L)*
42	0.003
42	0.0075
84	0.016
42	0.0075
42	0.003



View of Plume Looking Down

Source Halflife (see Help):

Inst. React.	1st Order	
8	8	(yr)

Soluble Mass 0.4 (Kg)
In Source Soil porewater

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)											
Dist. from Source (ft)	0	250	500	750	1000	1250	1500	1750	2000	2250	2500

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — View Output

RUN ARRAY — View Output

Help

Recalculate This

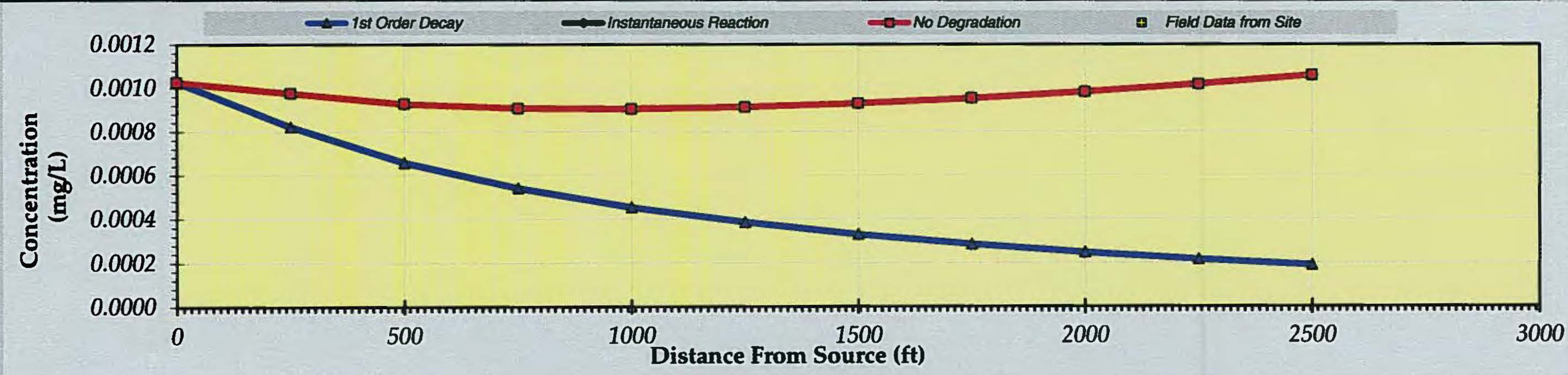
Paste Example Dataset

Restore Formulas for Vs,

CAL RUN C INPUT

ESTIMATE OF TIME TO REDUCE RESIDUAL TCE BELOW NJDEP GWQS IN UPPER AQUIFER (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	250	500	750	1000	1250	1500	1750	2000	2250	2500
No Degradation	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
1st Order Decay	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Field Data from Site											



Calculate Animation

estep

estep

Time:

30 Years

Return to

Recalculate This

RUN C INPUT PREDICTED TIME TO REDUCE RESIDUAL TCE BELOW NJDEP GWQS (mg/L at Z=0)

Transverse Distance (ft) ↓ / ***Distance from Source (ft)***

	0	250	500	750	1000	1250	1500	1750	2000	2250	2500
1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	1.0E+2	1.9E+1	1.5E+1	1.2E+1	1.0E+1	8.7E+0	7.4E+0	6.4E+0	5.6E+0	4.8E+0	4.2E+0

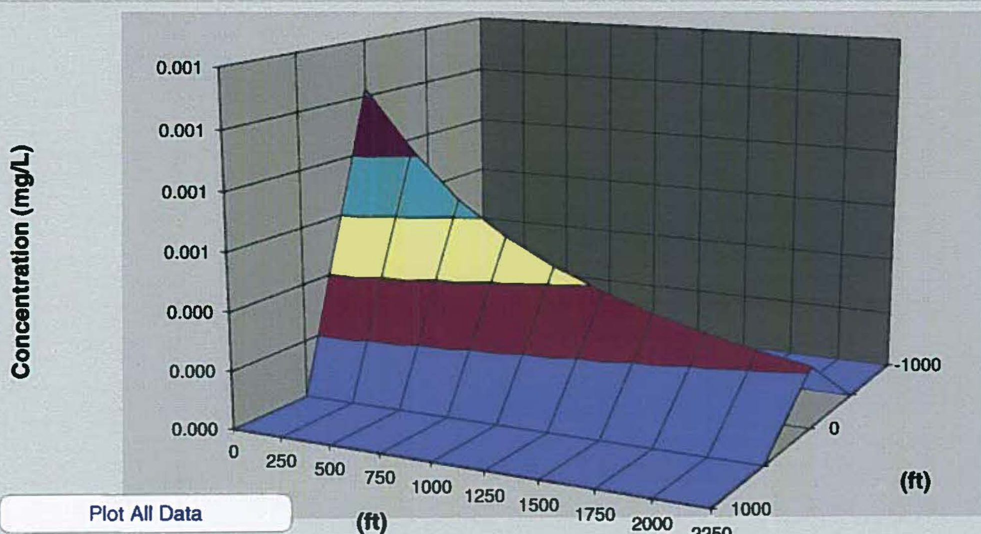
Time: **30 Years** Target Level: **0.001** mg/L Displayed Model: **1st Order Decay**

Model to Display:

No Degradation

1st Order Decay

Instantaneous



Plot All Data

Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation	Can't Calc.	*(Kg)*
- Actual Plume Mass	Can't Calc.	*(Kg)*
= Plume Mass Removed by Biodeg	-	*(Kg)*

Change in Electron Acceptor/Byproduct Masses:

Oxygen	*Nitrate*	*Iron II*	*Sulfate*	*Methane*	
na	na	na	na	na	*(Kg)*

Contam. Mass in Source (t=0 Years)	0.4	*(Kg)*
Contam. Mass in Source Now (t=30Years)	0.0	*(Kg)*
Current Volume of Groundwater in Plume	Can't Calc.	*(ac-ft)*
Flowrate of Water Through Source Zone	Can't Calc.	*(ac-ft/yr)*

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